Evaluation of Vertical Multiphase Flow Correlations for Saudi Arabian Field Conditions

by

Ahmed J. Al-Muraikhi

A Thesis Presented to the

FACULTY OF THE COLLEGE OF GRADUATE STUDIES

KING FAHD UNIVERSITY OF PETROLEUM & MINERALS

DHAHRAN, SAUDI ARABIA

In Partial Fulfillment of the
Requirements for the Degree of

MASTER OF SCIENCE

In

PETROLEUM ENGINEERING

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This thesis, written by Mr. Ahmad Jummah Al-Muraikhi under the direction of his Thesis Advisor and approved by his Thesis Committee, has been presented to and accepted by the Dean of the College of Graduate Studies, in partial fulfillment of the requirements for the degree of MASTER OF SCIENCE in Petroleum Engineering.

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خلاصة الرسالة

اسم الطالب : أحمد جمعه محمد المريخي

عنوان الدراسة : تقييم علاقات الانسياب العمودية المتعددة الأوجه لحقول البترول في المملكة العربية السعودية .

التخصص : هندسة بترول .

تاريخ الشهادة : يونيو ١٩٨٩م

لقد تم اجراء دراسة مقارنة بين العلاقات التبادلية المستخدمة في السريان العمودي للموائع المتعددة الأوجه وبين قياس الضغوط في حقول البترول وذلك بهدف تحديد علاقة تبادلية لظروف حقول البترول في المملكة العربية السعودية .

ولقد تمت مقارنة العلاقات المختلفة مع ٤١٤ من القياسات الحقلية من أنابيب ذات أقطار تتراوح قيمتها مابين ٢٫٣٧٥ و ٧٫٠ بوصة . وقد تراوح معدل سريان البترول اليومي بين ٢٨٠ برميل الى ٢٣٫٢٠٠ برميل . كما تراوحت نسبة وجود الماء في الموائع الى ٩٥٪ ووصلت نسبة الغاز الى البترول ٩٢٧ قدم مكعب لكل برميل .

ولقد تم تحليل العلاقة التبادلية لعزيز وقوفيير ، وهيجيدورن وبراون ، ودانز و روز ، وحسن وكبير ، وأوركزويسكي ، وبيغز وبريل . هذا بالاضافة الى دراسة بعض التحسينات على بعض العلاقات التبادلية وذلك باستخدام خرائط جديدة لتوزيع الغاز والسائل مثل خارطة دكلر وخارطة ويزمن وكانن . كما ان خارطة أوركزويسكي و دانز وروز قد استخدمت في العلاقة التبادلية لعزيز وقوفيير .

لقد وجد أن علاقة بيغز وبريل التبادلية تعطي أفضل التنبوءات لفارق الضغط عند استخدام جميع القياسات .

كذلك وجد أن العلاقة التبادلية لهيجدورن وبراون تعطي أفضل التنبوءات لفارق الضغط عندما تكون نسبة الماء أكثر من ٨٠٪ . بينما العلاقة التبادلية لكبير وحسن تعطي أفضل النتائج لفارق الضغط عندما يكون سريان البترول اليومي أكبر من ٢٠٫٠٠٠ برميل .

درجة الماجستير في العلوم

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THESIS ABSTRACT

Full Name of Student: Ahmad Jumah Al-Muraikhi

Title of Study: EVALUATION OF VERTICAL MULTIPHASE FLOW CORRELATIONS FOR SAUDI ARABIAN FIELD CONDITIONS

Date of Degree: June 1989

The most widely used vertical multiphase flow correlations have been tested against field measurements to determine the best correlations for Saudi Arabian field conditions.

A total of 414 field data points covering pipe sizes from 2.375 in. to 7.0 in., oil flow rate from 280 to 23,200 BPD, water cut up to 95%, and gas-oil ratio up to 927 SCF/STB were used in this study.

The standard correlations of Aziz and Govier, Hagedorn and Brown, Duns and Ros, Hasan and Kabir, Orkiszewski and Beggs and Brill were tested. In addition, attempts to improve some of the above correlations using the more recent flow pattern maps of Dukler, and Weisman and Kang has been performed. Furthermore, the Orkiszewski, and Duns and Ros flow pattern transition criteria were incorporated in Aziz and Govier correlations and tested.

The standard Beggs and Brill correlation provided the best predictions considering all data combined. However, Hagedorn and Brown correlation provided better predictions for water cuts above 80%, while Kabir and Hasan correlation provided better predictions for total liquid rate higher than 20,000 BPD.

MASTER OF SCIENCE DEGREE

KING FAHD UNIVERSITY OF PETROLEUM AND MINERALS
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CHAPTER 1

INTRODUCTION

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Multiphase flow, the simultaneous flow of gas and liquid phases in pipes, is encountered in almost all phases of oil and gas production. In general, oil, water and gas mixtures may exist in the wellbore and surface flowlines and facilities. The ability to predict pressure drop in multiphase flow is extremely important in well completion design, well performance evaluation, design of artificial lift installation and sizing of flow lines.

This, however, is a difficult task compared to the determination of pressure drop in single phase flow. Multiphase flow is a complex phenomenon because of the interdependence of the variables affecting pressure drop such as the flow pattern, hold up, the flow geometry (horizontal, vertical or inclined), the flow rate of each phase, and the fluid properties of the phases.

Because of this complexity, general analytical solutions for determining pressure drop in multiphase flow were never developed. Instead, empirical and semi-empirical correlations were developed for the various flow geometries. Some of these correlations are limited by either the range of variables under which they were developed, or by the applicable flow pattern (bubble, slug, churn or annular). Other correlations were claimed to be general correlations. Several multiphase flow correlations exist and have been tested and used in field applications. The vertical flow correlations which have seen extensive applications are those of Hagedorn and Brown [28], Duns and Ros [17], Orkiszewski [39], Beggs and Brill [4], and Aziz and Govier [1]. For horizontal flow, the correlations of Baker [2], Dukler [15], Eaton [18], Lockhart and Markinelli [35], and Beggs and Brill [4] have all been in use. The correlations of Flanigan [21] and Beggs and Brill [4] are probably the most successful for inclined flow. Most of these correlations depend on the use of specific holdup and flow pattern correlations.

Experience has shown, however, that the accuracy of these correlations vary from one field to another. Further, while one correlation may work for a particular area in the field, it may fail in another area in the same field. This is mainly because these correlations depend, to a large extent, on the tubing size and flow rates.

The above mentioned correlations have been developed and tested for tubing and flowline sizes and flowrates which are much smaller than those found in Saudi Arabian fields. These correlations are, therefore, not recommended for use in Saudi Arabian fields unless they are tested against actual field data.

The main purpose of this study is to test the available vertical multiphase flow correlations against Saudi Arabian field conditions, and determine the best correlations for the specific conditions of Saudi Arabian fields. Further, attempts have been made to improve certain vertical multiphase flow correlations by employing appropriate methods for predicting flow pattern transitions.

CHAPTER 2

LITERATURE REVIEW

Chapter 2
LITERATURE REVIEW

Many publications exist on the prediction of pressure losses in vertical multiphase flow in pipes. A few studies have been also made to evaluate and compare existing correlations. In this chapter, a review of the existing correlations is first presented; then the published comparative studies are reviewed.

2.1 Review of Correlations

Several correlations exist for determining pressure drop in vertical multiphase flow. Some correlations were developed for specific conditions covering a low range of variables. Such correlations are discussed here under Low Range Correlations. Other correlations were developed from field and experimental data covering a limited range of variables. These correlations are discussed under Limited Correlations. The third type represents the correlations which were developed from both experimental data and theoretical approaches, and employed holdup and flow pattern correlations. Such correlations have been extensively tested and are considered to be the best available correlatons. These correlations will be discussed in more details.

2.1.1 Low Range Correlations

One of the earliest studies to calculate or estimate the pressure losses in multiphase flow was by Davis and Weidner [13] in 1914. The purpose of their study was to determine the pressure losses due to friction in vertical pipes. A 1-1/4 inch pipe, and air and water were used. They noticed that increasing the amount of air injected increases the water discharge up to a certain air rate at which any additional air causes the water discharged to decrease. They concluded that this decrease in water discharged was due to friction losses. They also concluded that the amount of friction losses is a function of pipe roughness.

Verslays [46] in 1932 presented a theoretical analysis to define the conditions at which the mist and the foam flow exist. He defined mist conditions as existing when 50 percnet or more of the volume is occupied by gas, while the foam condition exists when gas bubbles are in the liquid mass while the liquid occupies the greater portion of the volume. He noted that the velocity difference between air and liquid increased with increasing the rate of air flow. He also noted that the gas bubbles rise in oil at a rate of about 8 in/sec with the rate depending on liquid viscosity.

Gilbert [23] in 1954 was the first investigator to present pressure gradient curves. His work was based on an empirical approach developed from field data using 2", 2-1/2" and 3" tubing. His curves are generally accurate at low rates.

Tek [45] in 1960 developed a semi-empirical vertical multiphase flow correlation based on a two phase friction factor which was developed for horizontal multiphase flow by Bertuzzi, Tek and Poettmann [6]. In his work, he used 2, 2-1/2 and 3 inches tubings and tested the correlation against low-rate wells producing less than 500 BPD.

2.1.2 Limited Correlations

Poettmann and Carpenter [40] in 1952 developed a semi-empirical correlation based on 2, 2-1/2 and 3 inches tubings and data from 34 flowing wells and 15 gas-lift wells. They treated the mixture of gas, oil and water as a single homogeneous phase and did not consider the effects of holdup and flow pattern. The liquid viscosity, the gas liquid ratio and the effect of the kinetic energy were neglected. Their correlation was based on the assumption that all the significant energy losses can be combined into a fanning-type friction factor. The energy loss term was correlated with the numerator of the Reynolds number to find the friction factor. This correlation is good within the ranges of the data used to develop it; i.e., tubing size between 2 and 3 inches, viscosity less than 5 cp, gas liquid ratio less than 1500 SCF/STB, and flow rate higher than 400 BPD.

Fancher and Brown [20] in 1963 extended the work of Poettmann and Carpenter to account for lower rates and higher gas liquid ratios. Their correlation was based on a 2" tubing and 8000 ft test well. They developed a friction factor correlation similar to Poettmann and Carpenter correlation but for different ranges of gas liquid ratio. This correlation is considered to be more accurate for lower rates and higher gas liquid ratios than Poettmann and Carpenter correlation.

Hagedorn and Brown [28] in 1964 developed a correlation which is considered to be an extension to Poettman and Carpenter correlation taking into account the viscosity effects. In their field experimental work, a 1500 ft long, 1-1/4 inch diameter tubing was used; water and four different fluids having viscosities of 0.86, 10, 35 and 110 cp were tested. They conlcuded that the effect of the viscosity is significant for viscosity values greater than 12 cp. They developed two correlations to calculate the friction factor; one for viscosity greater than 12 cp and the other for viscosity values less than 12 cp. The gas liquid ratio was also included in the correlation as a parameter in order to calculate the friction factor.

2.1.3 Most Commonly Used Correlations

(1) Aziz and Govier [1] Correlation (1972)

Aziz and Govier reviewed several methods for flow pattern identification and concluded that the work of Govier, Rodford and Dunn [24] is the most suitable. Four different flow patterns, i.e. bubble, slug, transition and mist, were identified. The flow regimes were defined using the following dimensionless variables:

$$N_x = V_{sg} \left(\frac{\rho_g}{0.0764}\right)^{1/3} \left(\frac{72\ \rho_L}{62.4\ \sigma_L}\right)^{1/4}$$

$$N_y = V_{sl} \left(\frac{72\ \rho_L}{62.4\ \sigma_L}\right)^{1/4}$$

$$N_1 = 0.51\ (100\ N_y)^{0.172}$$

$$N_2 = 8.60 + 3.8\ N_y$$

$$N_3 = 70\ (100\ N_y)^{-0.152}$$

where

V_{sg} = gas superfacial velocity, ft/sec (m/sec)

ρ_g = gas density, lbm/ft^3 (kg/m^3)

ρ_L = liquid density, lbm/ft^3 (kg/m^3)

σ_L = liquid interfacial tension, lbm/sec^2 (kg/sec^2)

V_{SL} = liquid superfacial velocity, ft/sec (m/sec)

The flow regimes limits were:

Bubble Flow:

$$N_y < N_1$$

Slug Flow:

$$N_1 < N_x < N_2 \quad \text{for} \quad N_y < 4,$$

$$N_1 < N_x < 26.5 \quad \text{for} \quad N_y \geq 4$$

Transition Flow:

$$N_2 < N_x < N_3 \quad \text{for} \quad N_y < 4$$

Mist Flow:

$$N_x > N_3 \quad \text{for} \quad N_y < 4$$

$$N_y > 26.5 \quad \text{for} \quad N_y > 4$$

The two phase density for the bubble and slug flows was given as:

$$\Delta P_s = \frac{dP}{dz} \rho_m \Delta Z$$

$$\rho_m = H_L \rho_L + (1 - H_L) \rho_g$$

$$H_L = 1 - \frac{V_{sg}}{V_{bf}}$$

where

ρ_m = the mixture density, lbm/ft^3 (kg/m^3)

ΔZ = depth increment

H_L = hold up

V_{bf} = bubble rise velocity under flowing condition, ft/sec(m/sec)

Different methods were used to calculate the rise velocity of the bubbles under stagnant (V_{bs}) and flowing (V_{bf}) conditions.

For bubble flow, the Zuber and Findlay [51] equations shown below were used:

$$V_{bs} = 1.41 \left(\frac{\sigma_L\, g\, (\rho_L - \rho_g)}{\rho_L^2}\right)^{1/4}$$

$$V_{bf} = 1.2\ V_m + V_{bs}$$

where V_{bs} is the bubble rise velocity under the stagnant condition, ft/sec (m/sec).

For slug flow, the Neal [38] and Wallis [49] methods were used:

$$V_{bs} = C\left[\frac{g\ d\ (\rho_L - \rho_g)}{\rho_L}\right]^{1/2}$$

where

$$C = 0.345\ [1\text{-EXP}(0.029)NV]\ [1 - \text{EXP}\ (\frac{3.37 - NE}{m})]$$

$$NE = \frac{g\ d^2\ (\rho_L - \rho_g)}{\sigma_L}$$

$$NV = \left[\frac{[d^3\ g\ \rho_L(\rho_L - \rho_g)]^{1/2}}{\mu_L}\right]$$

where

d = inside tubing diameter, ft(m)

g = gravitational acceleration, ft/sec^2(m/sec^2)

μ_L = liquid viscosity, lbm/sec ft

m is evaluated by:

$$m = 10 \quad \text{for} \quad NV \geq 250$$

$$= 69\ NV^{-0.35} \quad \text{for} \quad 18 < NV < 250$$

$$= 25 \quad \text{for} \quad NV \leq 18$$

where

NV = Wallis liquid viscosity number

NE = Eotvos number

The acceleration term was considered to be negligible in the bubble and the slug flow regimes.

To calculate the pressure gradient for the transition region, the pressure gradients must be calculated using both the slug flow equations and the mist flow equations; linear interpolation is then performed as follows:

$$\Delta P_s = \frac{dP}{dz} = A\left(\frac{dP}{dz}\right)_{slug} + B\left(\frac{dP}{dz}\right)_{mist}$$

where

$$A = \frac{N_3 - N_x}{N_3 - N_2}, \quad B = \frac{N_x - N_2}{N_3 - N_2}$$

where

N_2 = dimensionless boundary limit

N_3 = dimensionless boundary limit

N_x = dimensionless group

The Colebrook [12] friction factor equation was used to calculate the pressure drop due to frictions:

$$\frac{1}{\sqrt{f}} = 4 \log \frac{d}{2}\varepsilon + 3.48 - 4 \log \left(1 + 9.35 \frac{d}{2\varepsilon \, R_e \sqrt{f}}\right)$$

where

f = friction factor

ε = 0.00015

R_e = Reynolds number

To calculate the friction factor for the bubble flow, the friction gradient is given as:

$$\left(\frac{dP}{dz}\right)_f = \frac{f \, \rho_m \, V_m^2}{2 \, g_c \, d}$$

where

ρ_m = mixture density, lbm/ft^3 (kg/m^3)

V_m = mixture velocity, ft/sec (m/sec)

g_c = dimension conversion factor = 32.2 lbm ft/lbf sec^2

The Reynold Number is given as:

$$R_e = \frac{\rho_L V_m d}{\mu_L}$$

For the slug flow:

$$\left(\frac{dP}{dz}\right)_f = \frac{f \rho_L H_L V_m^2}{2 g_c d}$$

The total pressure drop gradient equation is:

$$\left(\frac{dP}{dZ}\right)_{TOT} = \left(\frac{dP}{dZ}\right)_f + \left(\frac{dP}{dZ}\right)_{st}$$

(2) Hagedorn and Brown [28] Correlation (1964)

This correlation was developed from experimental data covering wide ranges of flow rates and gas-liquid ratios, and accounting for viscosity effects. Different tubing sizes ranging from 1 inch to 2-1/2 inches were used. The general energy equation was used to obtain the pressure loss, which consists of three terms: The first is the pressure drop due to the weight of fluid under flowing conditions, the second is the pressure drop due to the friction and the third is the pressure drop due to acceleration. The flowing mixture density is calculated using the following equation:

$$\rho_m = \rho_L H_L + \rho_g (1 - H_L)$$

where

ρ_m = mixture density, $lbm/ft^3 (kg/m^3)$

ρ_L = liquid density, $lbm/ft^3 (kg/m^3)$

ρ_g = gas density, $lbm/ft^3 (kg/m^3)$

H_L = hold up

A pseudo holdup correlation was developed by back calculating the holdup from knowledge of the total pressure loss and a friction factor obtained from a two phase Reynolds number. A regression analysis technique was used to relate the liquid holdup (H_L) to four dimensionless groups. Two correlations were needed for the holdup and liquid viscosity.

The original correlation was not working for large pipes at low rates. Two adjustments were made by Brill and Hagedorn to improve the correlation. The first adjustment was made by calculating the mixture density using the hold up correlation and then to compare it to the mixture density for no slippage; the larger of the two densities is used. The second adjustment was to use the Griffith [26] correlation if bubble flow exists; in this case the holdup is calculated as follows:

$$H_L = 1 - 1/2\ [1 + \frac{q_t}{V_s\ A_p} - \sqrt{(1 + \frac{q_t}{V_s A_p})^2 - \frac{4\ q_g}{V_s A_p}}]$$

where

q_t = total liquid rate, $ft^3/sec(m^3/sec)$

V_s = slippage velocity, ft/sec (m/sec)

A_p = pipe cross-sectional area, $ft^2(m^2)$

q_g = gas rate, $ft^3/sec(m^3/sec)$

The pressure loss due to friction is calculated using the following equation:

$$144\ (\frac{\Delta P}{\Delta Z})_f = \frac{f\ w^2}{2.9652 \times 10^{11}\ d^5\ \rho_m}$$

where

f = friction factor

w = the mass flow rate (lbm/day)

d = inside tubing diameter, ft (m)

The Reynolds number for the two phase mixture was defined using Arrhenius equation for the mixture viscosity, as follows:

$$R_{e_{t.p.}} = 2.2 \times 10^{-2} \frac{W}{d\ \mu_L^{H_L}\ \mu_g^{(1-H_L)}}$$

where

μ_L = liquid viscosity, lbm/sec-ft

μ_g = gas viscosity, lbm/sec-ft

A relationship between the above Reynolds number and the friction factor was developed as shown in Fig. 2.1. The pressure loss due to acceleration is calculated using the kinetic energy equation:

$$144\ (\frac{\Delta P}{\Delta Z})_{acc} = \rho_m\ (\frac{V_m^2}{2\ g_c/h})$$

where

V_m = mixture velocity, ft/sec (m/sec)

g_c = dimension conversion factor = 32.2 lbm ft/lbf sec^2

The pressure loss due to kinetic energy is considered to be very significant in small diameter pipes in the region near the surface where the fluid has a low density.

The total pressure drop gradient equation is:

$$(\frac{\Delta P}{\Delta Z})_{TOT} = \rho_m + (\frac{\Delta P}{\Delta Z})_f + (\frac{\Delta P}{\Delta Z})_{acc}$$

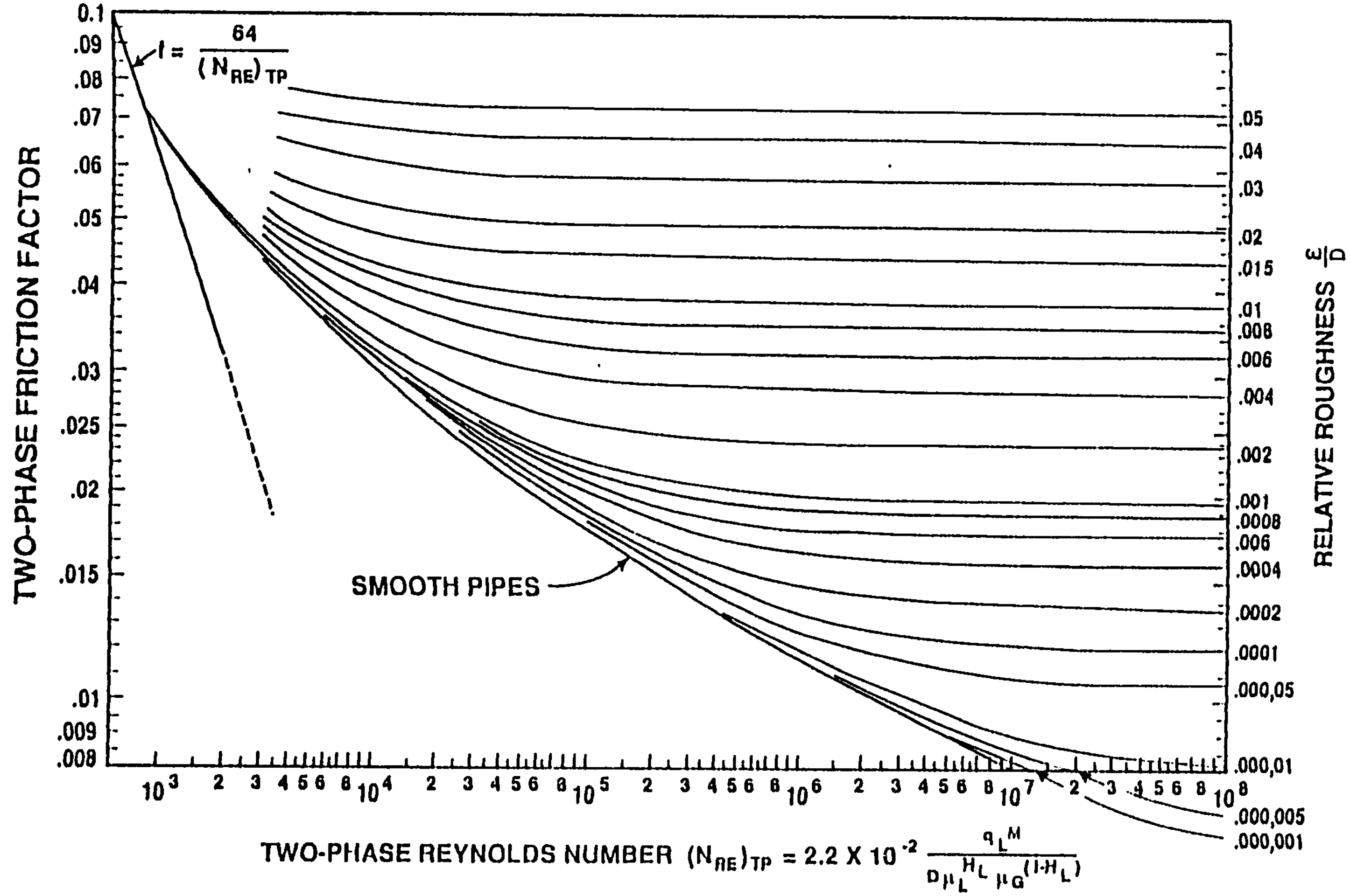

FIG. 2.1: HAGEDORN FRICTION FACTOR CORRELATION CURVES.

(3) **Orkiszewski Correlation [39] (1965)**

Orkiszewski analyzed the available correlations and tested them against field data. He concluded that no one correlation is sufficiently accurate for all flow regimes and conditions. He then selected what he considered to be the most accurate correlations for each flow pattern. He identified four different flow patterns; namely bubbles, slug, transition and mist flows.

He recommended Griffith [26] (1962) correlation for the bubble flow. For mist flow, he recommended the Duns and Ros [17] correlation. Different correlations for slippage velocity and friction factor were developed for each flow regime. Furthermore, he recommended the Griffith and Wallis [25] correlation for slug flow, after extending it to include the high velocity flow ranges. For the density in the transition flow, he recommended the Duns and Ros [17] interpolation method to interpolate between the slug and the mist regimes:

$$\rho = \frac{L_m - V_{gd}}{L_m - L_s} \rho_{slug} + \frac{V_{gd} - L_s}{L_m - L_s} \rho_{mist}$$

Orkiszewski expressed the pressure drop as:

$$\frac{\Delta P}{\Delta Z} = \frac{1}{144} \left[\frac{\rho + \tau_f}{1 - \dfrac{W_t \, q_g}{4637 \, A_p^2 \, P}} \right]$$

The flow regime limits are:

For bubble, $\frac{q_g}{q_t} < (L_b)$

For slug, $\frac{q_g}{q_t} > (L_b)$, $V_{gd} < (L_s)$

For transition, $(L_m) > V_{gd} > (L_s)$

For mist, $V_{gd} > (L_m)$

where

$$V_{gd} = q_g \frac{(\rho_L/g\sigma_L)^{1/4}}{A_p}$$

$$L_b = 1.071 - \frac{(0.2218\ V_m^2)}{d} \qquad \text{for } (L_b) > 0.13$$

$$L_{slug} = 50 + 36\ V_{gd} \frac{q_L}{q_g}$$

$$L_{mist} = 75 + 84\ (V_{gd} \frac{q_L}{q_g})^{0.75}$$

where

L_b = bubble-slug boundary, dimensionless

L_s = slug-transition boundary, dimensionless

L_m = transition-mist boundary, dimensionless

ρ_{slug} = fluid density in the slug regime, $lbm/ft^3 (kg/m^3)$

ρ_{mist} = fluid density in the mist regime, $lbm/ft^3 (kg/m^3)$

ρ = fluid density, $lbm/ft^3 (kg/m^3)$

V_{gd} = dimensionless gas velocity

τ_f = wall friction-loss term, $lbm/ft^2/ft$

W_t = total mass flow rate, lb/sec (kg/sec)

q_g = gas rate, $ft^3/sec (m^3/sec)$

q_t = total liquid rate, $ft^3/sec (m^3/sec)$

A_p = pipe cross-sectional area, $ft^2 (m^2)$

d = inside pipe diameter, ft(m)

P = average pressure, psi (gm/cm^2)

σ_L = liquid interfacial tension, $lbm/sec^2 (kg/sec^2)$

g = gravitational acceleration, $ft/sec^2 (m/sec^2)$

ρ_L = liquid density, $lbm/sec^3 (kg/sec^3)$

V_m = mixture velocity, ft/sec (m/sec)

For slug flow, the average density is calculated as follows:

$$\rho = \frac{W_t + \rho_L V_{sb} A_p}{q_t + V_{sb} A_p} + \delta \rho_L$$

where V_{sb} is bubble rise velocity, ft/sec (m/sec) and δ is the liquid distribution coefficient which may be determined by the equation which meets the following conditions:

For water cut 75% or more and $V_m < 10$:

$$\delta = \left(\frac{0.013 \log \mu_L}{d^{1.38}}\right) - 0.681 + 0.232 \log V_m - 0.428 \log d$$

For water cut 75% or more and $V_m > 10$:

$$\delta = \left[\frac{(0.045 \log \mu_L)}{d^{0.799}}\right] - 0.709 - 0.162 \log V_m - 0.888 \log d$$

For water cut less than 75% and $V_m < 10$:

$$\delta = 0.0127 \log \left[\frac{(\mu_L + 1)}{d^{1.415}}\right] - 0.284 + 0.167 \log V_m + 0.113 \log d$$

For water cut less than 75% and $V_t > 10$:

$$\delta = 0.0274 \log \left[\frac{(\mu_L + 1)}{d^{1.371}}\right] + 0.161 + 0.569 \log d$$

$$- \log V_m \left[\frac{0.01 \log (\mu_L + 1)}{d^{1.571}} \right] + 0.397 + 0.63 \log d$$

$$V_{sb} = C_1 \, C_2 \, (gd)^{1/2}$$

C_1 is obtained from Fig. 2.2 as a function of bubble Reynolds number which is given as:

$$R_e = \frac{1488 \, V_{sb} \, d \, \rho_L}{\mu_L} ,$$

C_2 is expressed in Fig. 2.3 as a function of both N_b and liquid Reynolds number:

$$R_e = \frac{1488 \, \rho_L \, d \, V_m}{\mu_L}$$

When C_2 cannot be read from Fig. 2.3, the extrapolated values of V_s may be calculated by the following set of equations:

For $N_b \leq 3000$

$$V_{sb} = 0.546 + 8.74 * 10^{-6} R_e \, (gd)^{0.5}$$

For $3000 < N_b < 8000$

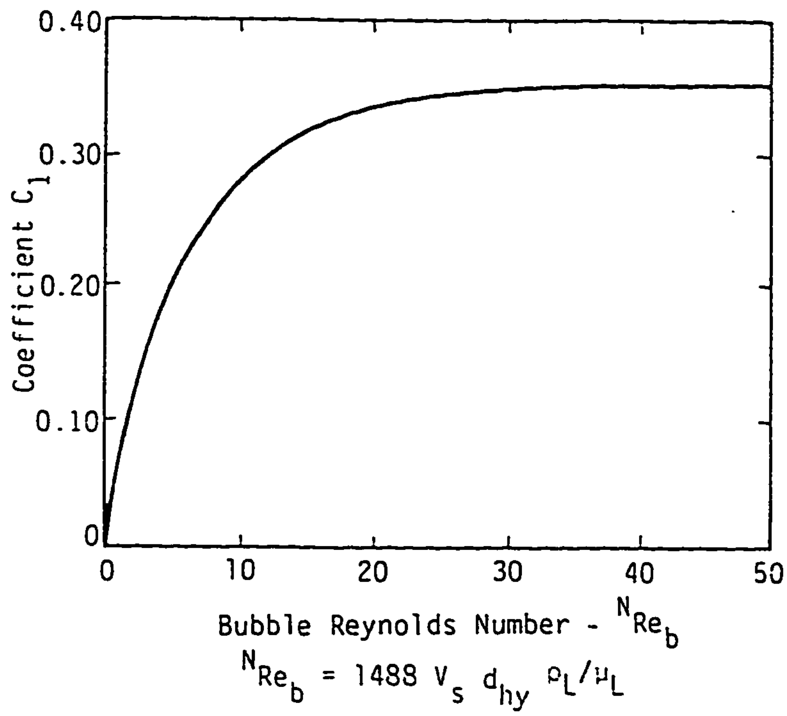

Fig. 2.2: Griffith and Wallis' C_1 vs. Bubble Reynolds Number.

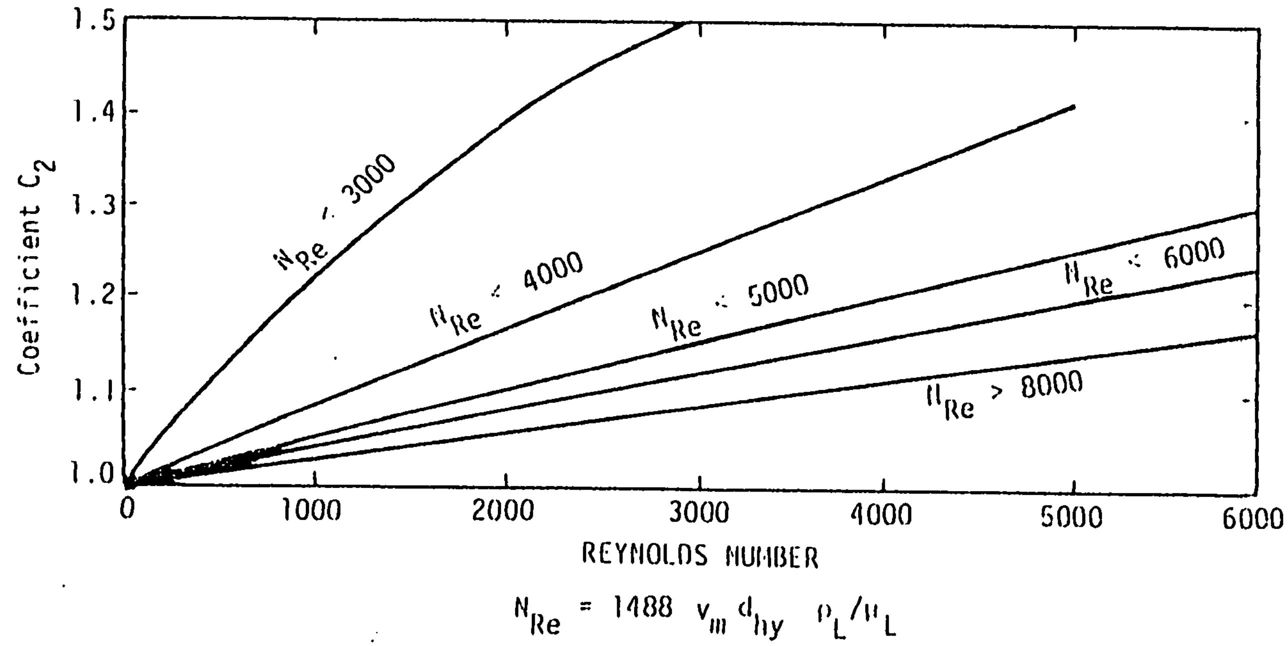

Fig. 2.3: Griffith and Wallis' C_2 vs. Bubble Reynolds Number.

$$V_{s_i} = (0.251 + 8.74 * 10^{-6} R_e) (gd)^{0.5}$$

$$V_{sb} = 1/2 [V_{s_i} + (V_{s_i}^2 + \frac{13.59 \mu_L}{\rho_L (d)^{.5}})^{0.5}]$$

For $N_b \geq 8000$

$$V_{sb} = (0.35 + 8.74 * 10^{-6} R_e) (gd)^{0.5}$$

The wall friction loss term is expressed as:

$$\tau_f = \frac{f \rho_L V_m^2}{2g_c d} [\frac{q_L + V_{sb} A_p}{q_t + V_{sb} A_p} + \delta]$$

The friction factor f is obtained from moody chart (Fig. 2.4).

The Reynolds number equation is:

$$R_e = \frac{1488 \rho_L d V_m}{\mu_L}$$

For mist flow, the wall friction loss term is expressed as:

$$\tau_f = \frac{f \rho_g V_g^2}{2 g_c d}$$

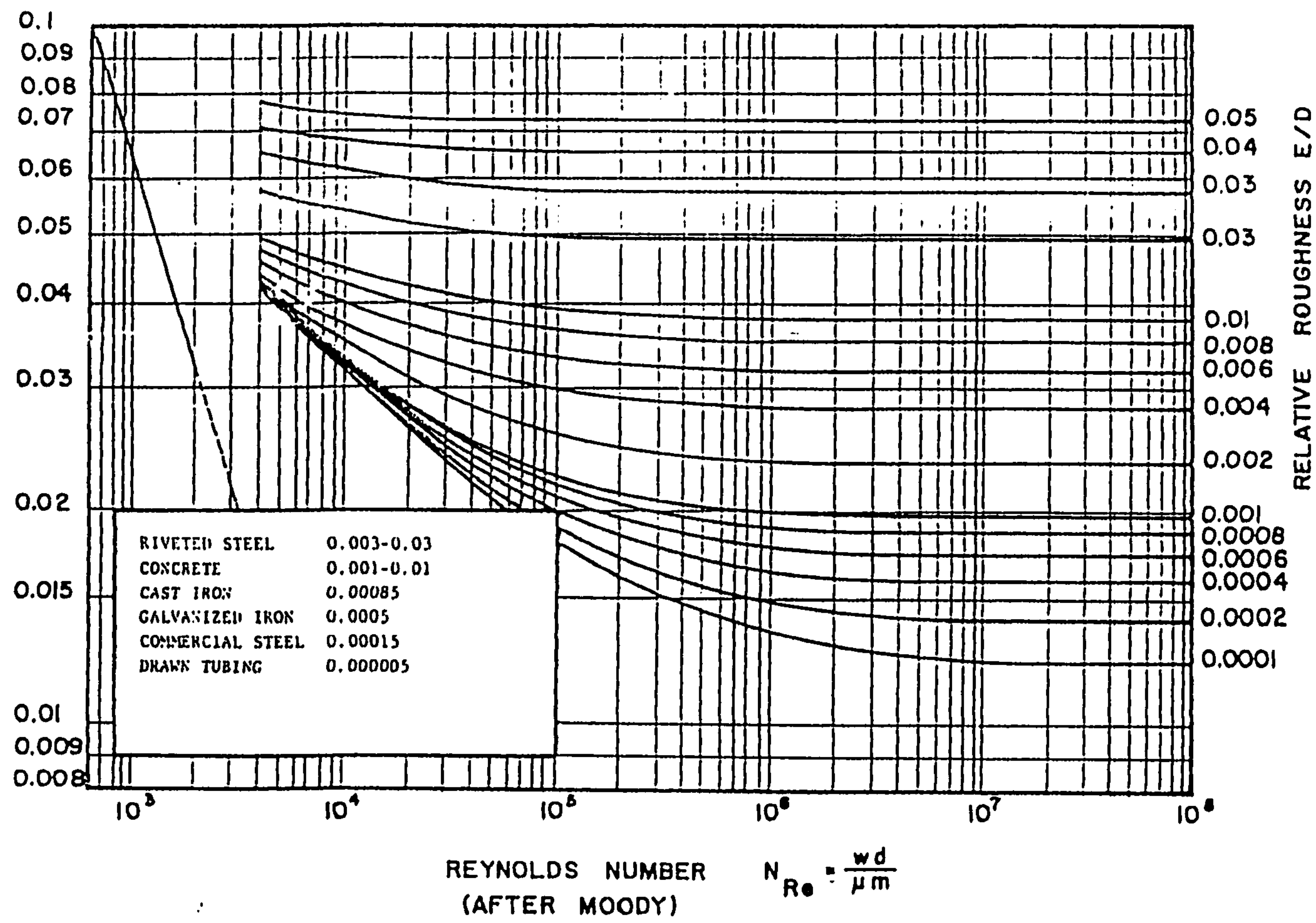

Fig. 2.4: Moody Friction Factor Curves.

and in the bubble flow, it is expressed as:

$$\tau_f = \frac{f \rho_L V_L^2}{2 g_c d}$$

(4) **Duns and Ros** [17] (1963)

This correlation was developed from an extensive laboratory study with modifications and adjustments using field data. Three different flow patterns were identified; bubble, slug and mist. Dimensionless groups were used to determine the flow patterns. The pressure balance equation is used to calculate the total gradient which includes a static gradient, a wall friction gradient and an acceleration gradient.

The effect of the slip between the gas and liquid phase were incorporated in the static gradient and were kept separate from the effects due to friction. Different methods to calculate the slip factor, the slip velocity and the Holdup were developed for each flow region.

Following are the equations used for each region:

Bubble Flow:

$$\text{Slip factor, } s = F_1 + F_2 N_{LV} + F_3' \left(\frac{N_{gv}}{1 - N_{LV}}\right)^2$$

$$F_3' = F_3 - \frac{F_4}{N_d}$$

$$\text{Slip velocity, } V_s = \frac{s}{1.938\,(\frac{\rho_L}{\sigma_L})^{0.5}}$$

where

F_1 , F_2 , F_3 , F_3' , F_4 , F_5 , F_6 , F_7 are dimensionless groups

N_{gv} = gas velocity number

N_{gL} = liquid velocity number

N_d = pipe diameter number

$$H_L = \frac{V_s - V_{sg} - V_{sL} + [(V_s - V_{sg} - V_{sL})^2 + (4\, V_s\, V_{sL})]^{0.5}}{2\, V_s}$$

Slug Flow:

$$\text{Slip factor, } s = (1 + F_5)\,\frac{(N_{gv})^{0.982} + F_6'}{(1 + F_7\, N_{LV})^2}$$

where $F_6' = 0.029\, N_d + F_6$

where F_6' = dimensionless number

F_1, F_2, F_3, and F_4 are obtained from Fig. 2.5, while F_5, F_6,

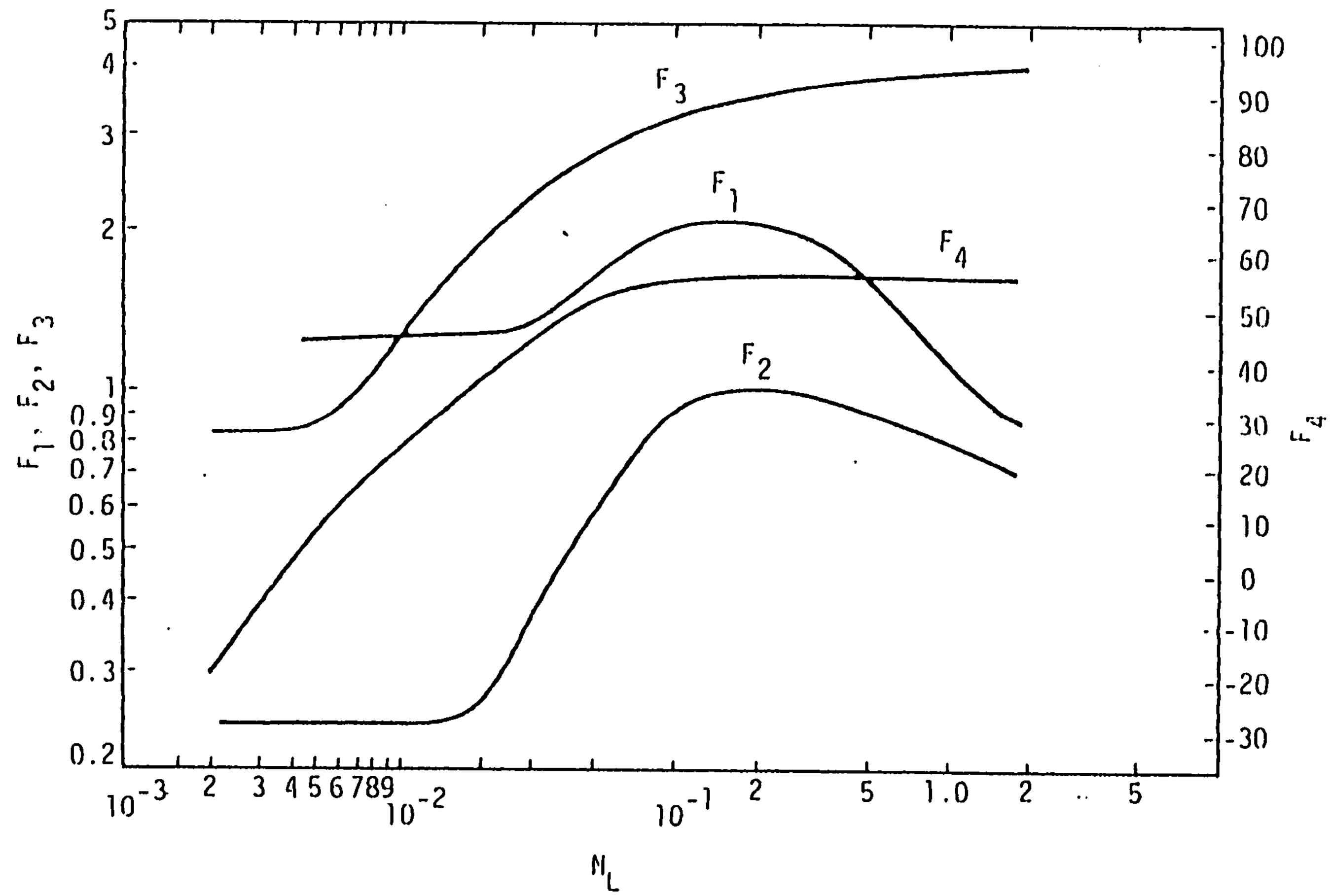

Fig. 2.5: F_1, F_2, F_3, and F_4 against Viscosity number N_L.

and F_7 are obtained from Fig. 2.6.

The slip velocity and the holdup are calcualted as in the bubble flow equations.

Mist Flow:

Slip factor, s = 0

$$H_L = \frac{1}{1 + \frac{V_{sg}}{V_{sL}}},$$

The static gradient due to mixture flowing density is given by:

$$G_{st} = H_L + (1 - H_L) \frac{\rho_g}{\rho_L}$$

where G_{st} is the fluid gradient.

The flow region is determined from the following criteria:

Bubble flow if : $0 \leq N_{gV} \leq (L_1 + L_2 N_{LV})$

Slug flow if : $L_1 + L_2 N_{LV} < N_{gV} < (50 + 36 N_{LV})$

Mist flow if : $N_{gV} > 75 + 84 N_{LV}^{0.75}$

L_1 and L_2 are obtained from Fig. 2.7.

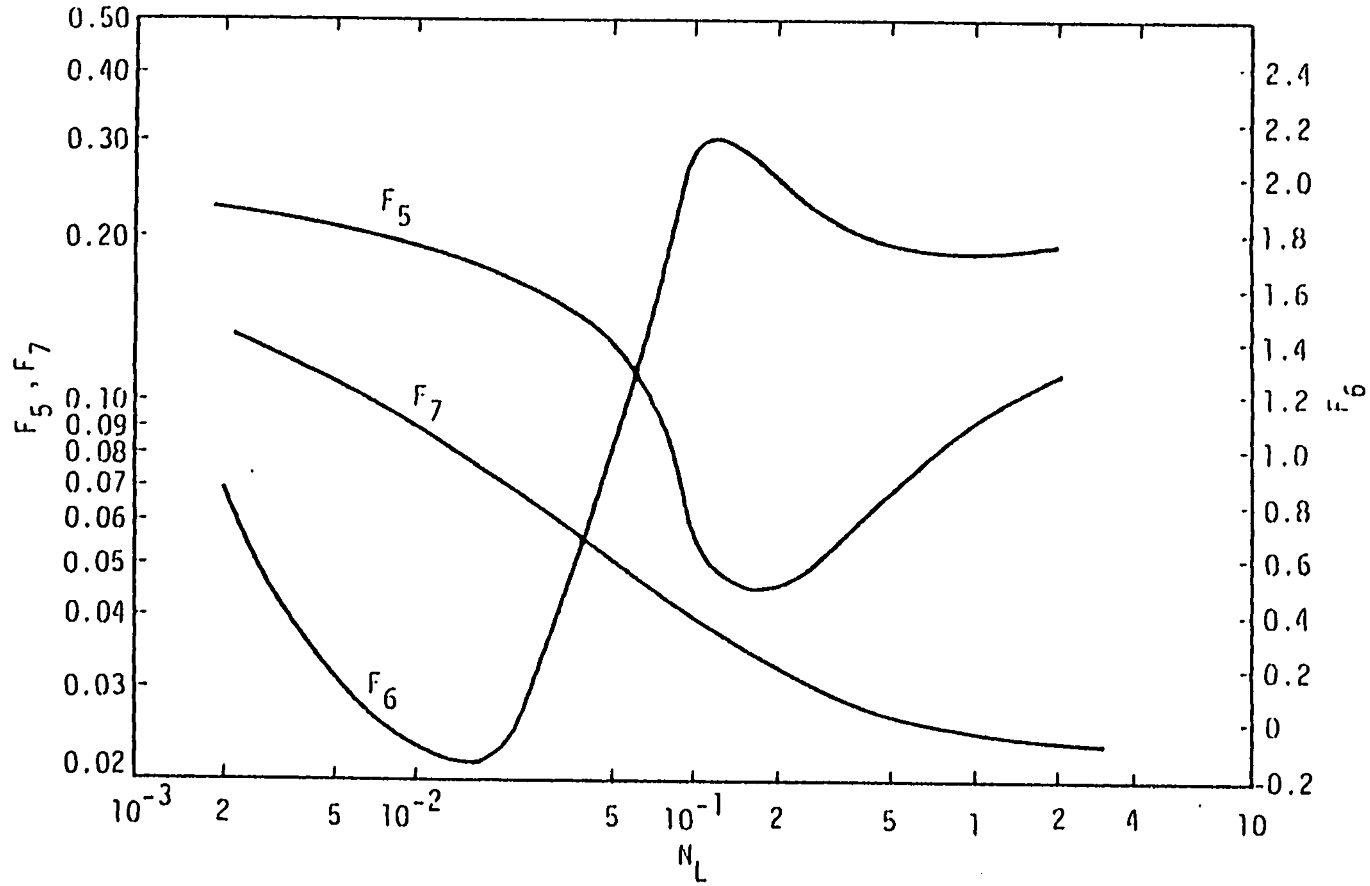

Fig. 2.6: F_5, F_6, and F_7, against Viscosity number N_L.

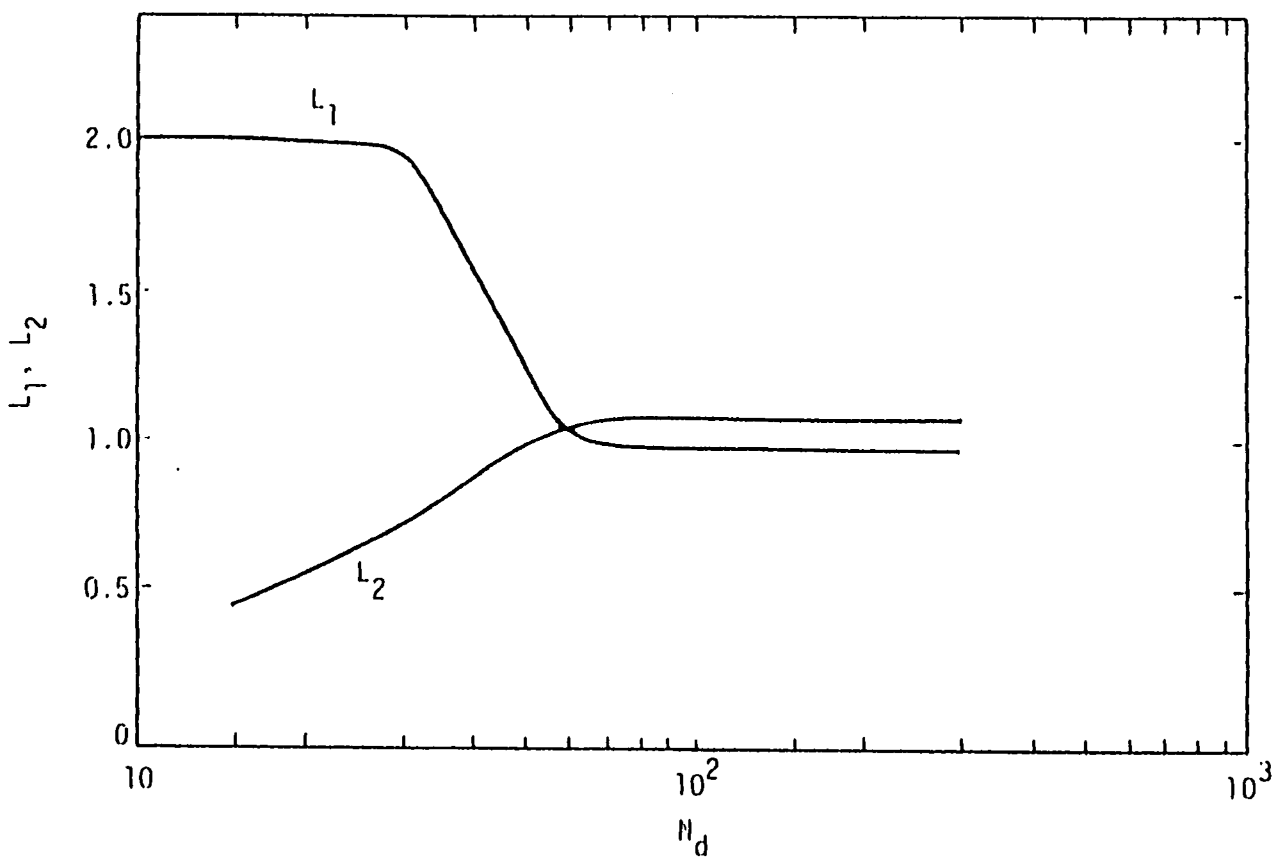

Fig. 2.7: L-Factors against Diameter Number N_d .

Three different friction factor correlations were also developed for the three flow regimes. For the bubble and slug regimes, the friction gradient is calculated using the following equations:

$$\left(\frac{dP}{dz}\right)_f = \frac{4\, f_w\, \rho_L\, V_{sL}^2}{2d}\left(1 + \frac{V_{sg}}{V_{sL}}\right)$$

where, Duns and Ros formulated f_w from the experimental data as follows:

$$f_w = \frac{f_1\, f_2}{f_3}$$

where f_1 is obtained from Fig. 2.8, f_2 is obtained from Fig. 2.9, and f_3, which is an additional correction to the liquid viscosity and the in situ gas liquid ratio equals to:

$$f_3 = 1 + f_1 \frac{R}{50}$$

where $R = \dfrac{V_{sg}}{V_{sL}}$

The Reynolds number is expressed as:

$$(R_e)_L = \rho_L \frac{V_{sL}}{\mu_L} d$$

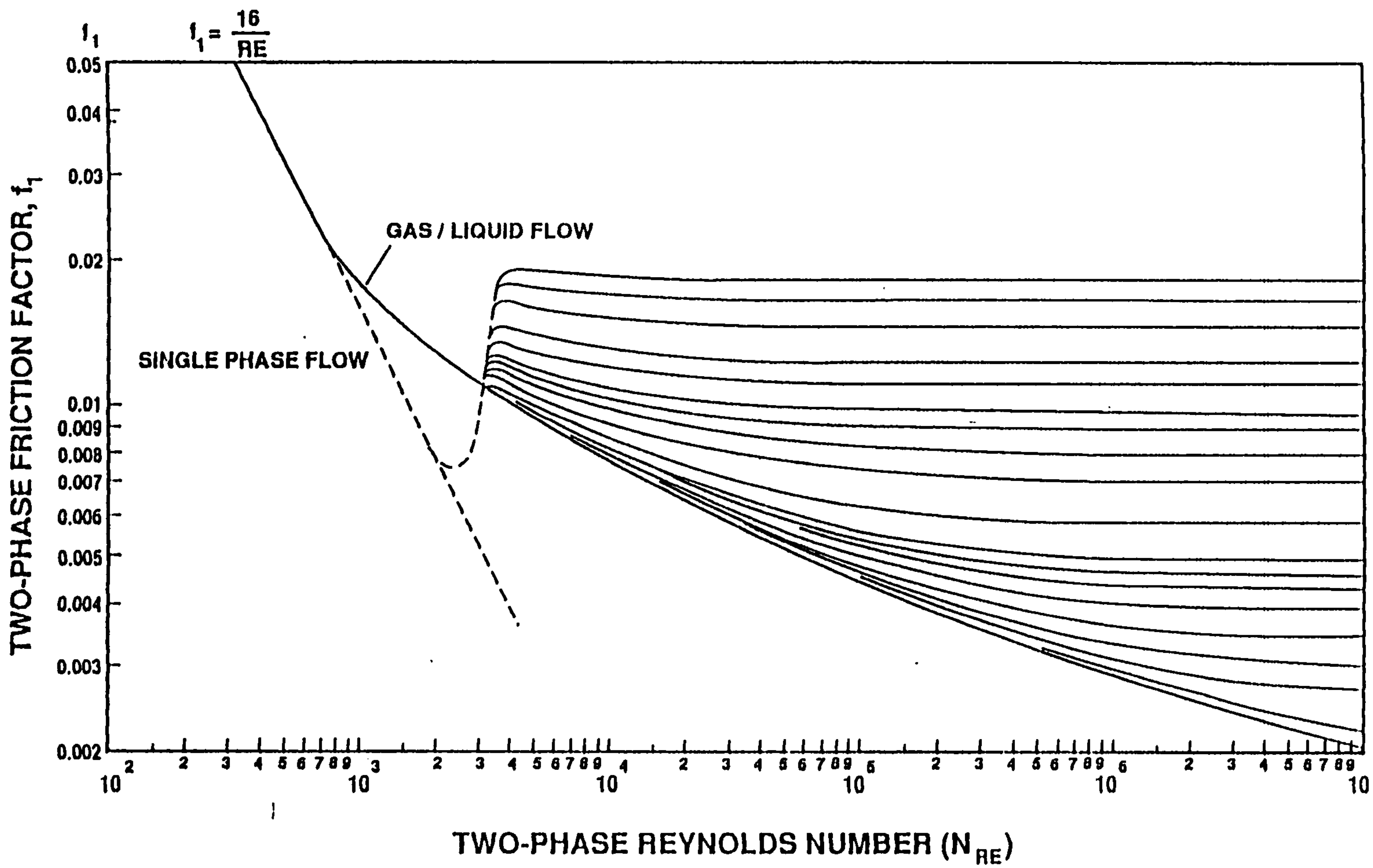

FIG. 2.8: ROS FRICTION FACTOR CURVES

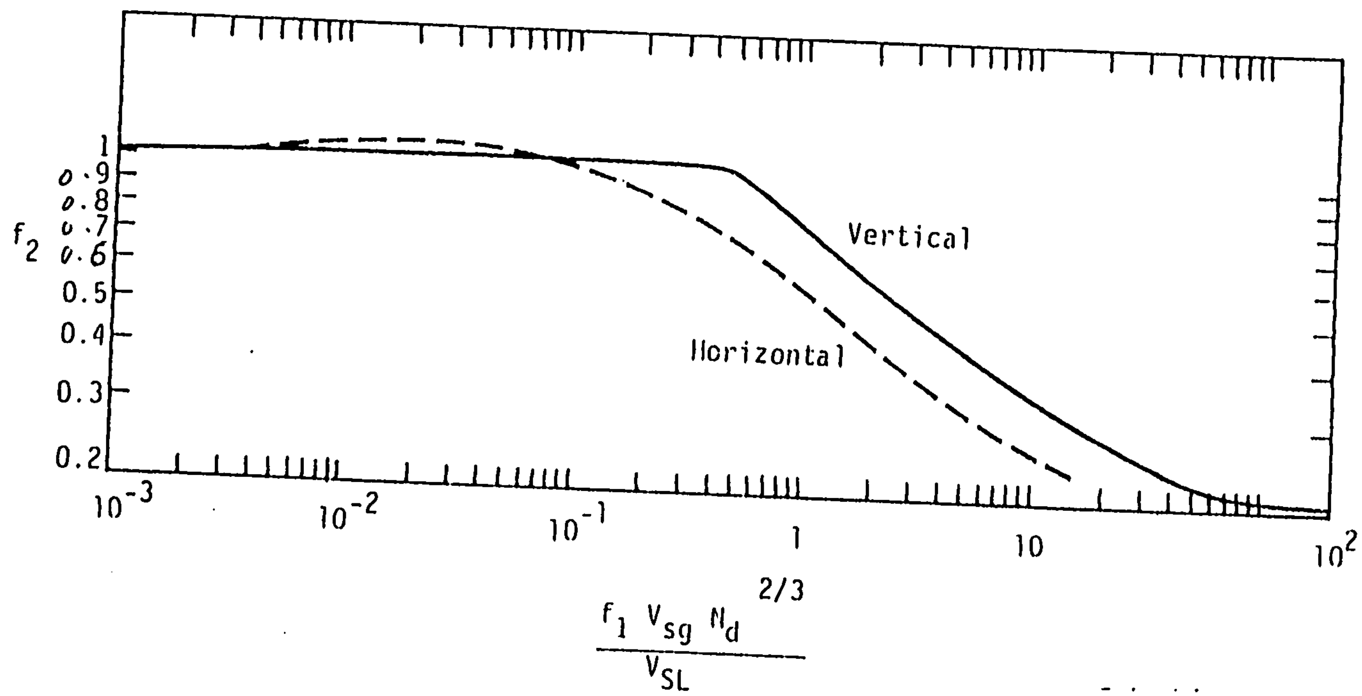

Fig. 2.9: **Bubble Friction Correction.**

The friction gradient in mist flow is calculated using the following equation:

$$\left(\frac{dP}{dz}\right)_f = \frac{4\, f_w\, \rho_g\, V_{sg}^2}{2d}$$

where f_w is taken to be equal to f_1, which is obtained from Fig. 2.8.

The Reynolds number is calculated using the gas velocity and density as follows:

$$(R_e)_g = \frac{\rho_g\, V_{sg}\, d}{\mu_g}$$

The pressure gradient due to friction equals to:

$$G_f = \frac{\left(\frac{dP}{dz}\right)_f * 144}{\rho_L}$$

The pressure gradient due to acceleration is calculated as follows:

$$G_{acc} = \frac{\rho_L V_{sL} + \rho_g\, V_{sg}}{V_{sg}}\, P$$

The total pressure gradient is equal to:

$$G_{TOT} = G_{st} + G_f + G_{acc}$$

(5) **Beggs and Brill Correlation** [4] (1973)

Beggs and Brill developed a correlation based on experimental data obtained in a small scale test facility. The facility consisted of 1 inch and 1.5 inches sections of acrylic pipe 90 feet long. The pipe could be inclined at any angle. Fluids used were air and water. For each pipe size, liquid and gas rates were varied, so that all flow patterns were observed when the pipe was horizontal. After a particular set of flow rates was set, the angle of the pipe was varied between 0 to ±90°, so that the effect of the inclination angle on holdup and pressure gradient can be observed. The liquid rate was varied between 0 - 30 gallon per minute. The gas rate was between 0 - 300 MSCFPD and the average system pressure was 35 - 95 psia. The observed holdup was between 0 - 0.87 and the pressure gradient was between 0 - 0.8 psi/ft. Four different flow patterns were observed in the horizontal flow (Fig. 2.10), these are segregated, transition, intermittent and distributed. The effect of the angle was observed on the pressure gradient and on the holdup. A holdup correlation for each flow pattern was developed. The holdup at any angle is calculated as a function of the horizontal holdup (Fig. 2.11). It was found that the holdup is maximum at an angle of +50° and is minimum at an angle of -50°. Froude number, the no slip holdup and dimensionless groups L_1 , L_2 , L_3 , and L_4 were used for flow pattern determination; these were given as follows:

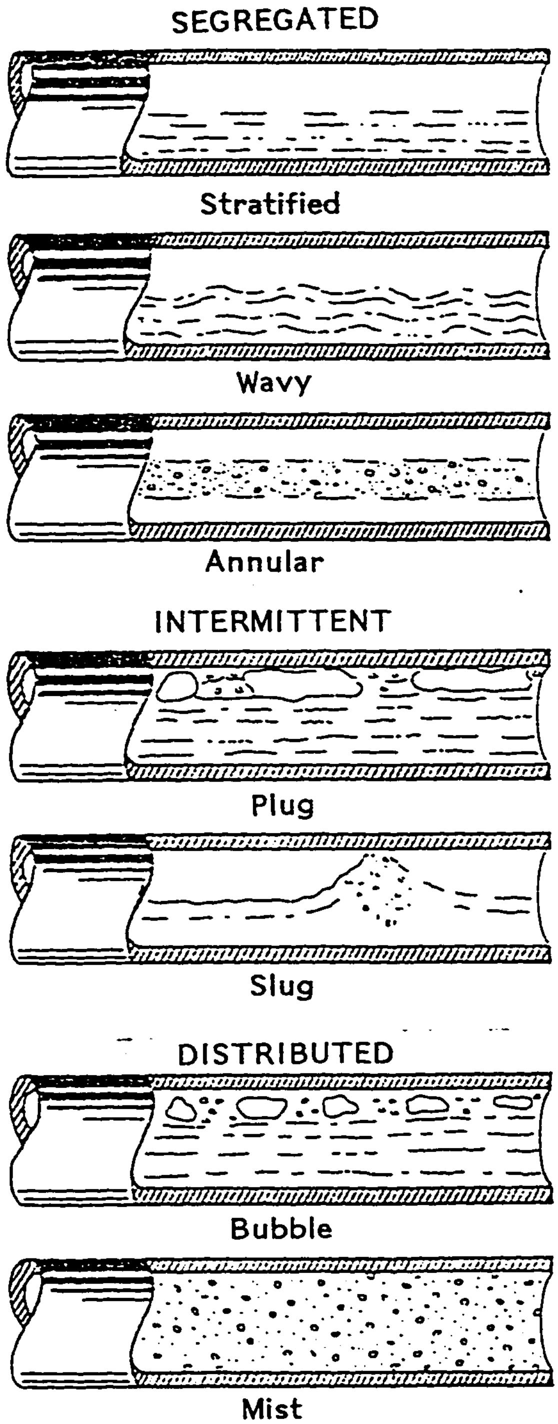

Fig. 2.10: Beggs and Brill Horizontal Flow Patterns.

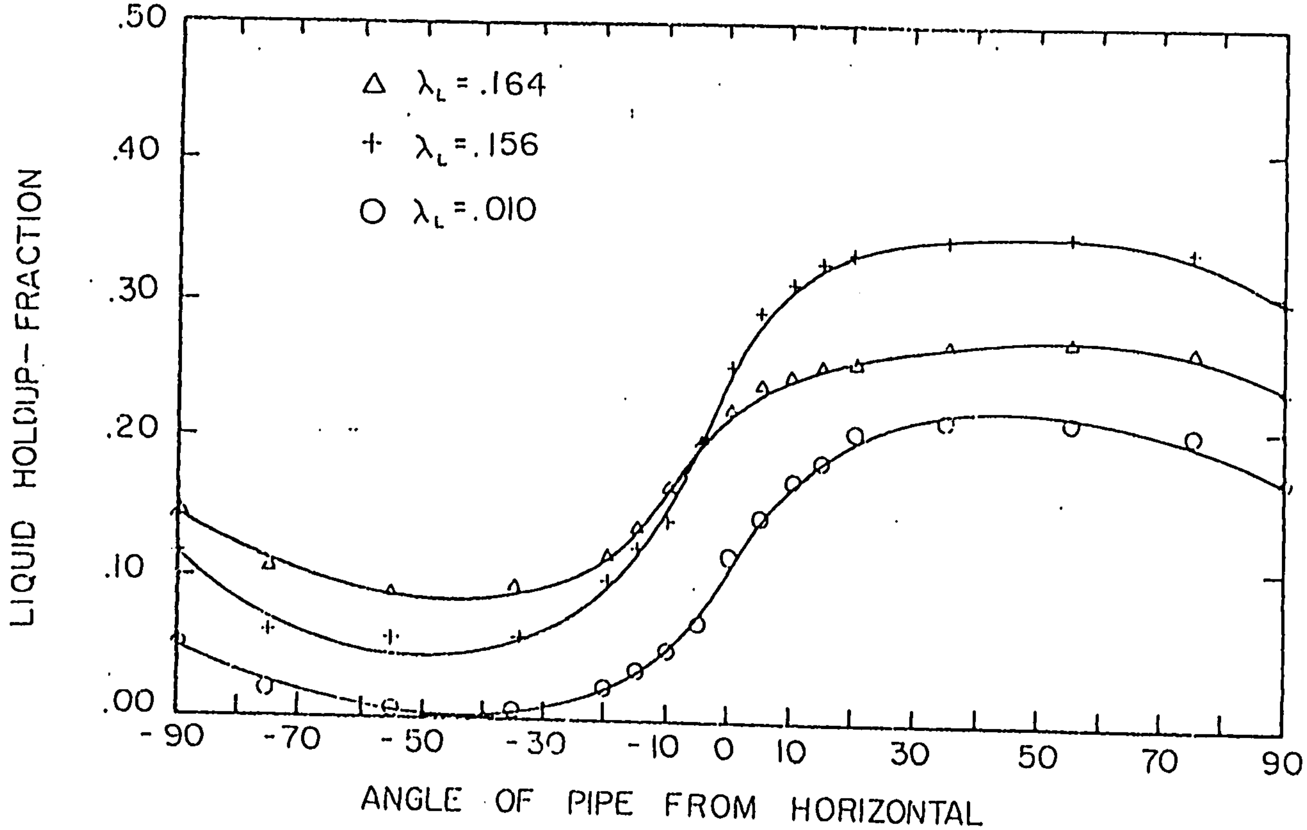

Fig. 2.11: Liquid Holdup vs. Angle.

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No Slip Holdup:

$$\lambda_L = \frac{V_{sL}}{V_m}$$

$$N_{FR} = \frac{V_m^2}{gd}$$

where

N_{FR} = Froude number

The Dimensionless Group:

$$L_1 = 316 \ \lambda_L^{0.302}$$

$$L_2 = 0.0009252 \ \lambda_L^{-2.4684}$$

$$L_3 = 0.10 \ \lambda_L^{-1.4516}$$

$$L_4 = 0.50 \ \lambda_L^{-6.738}$$

The horizontal flow regime limits are:

Segregated:

$$\lambda_L < 0.01 \quad \text{and} \quad N_{FR} < L_1$$

or

$$\lambda_L \geq 0.01 \text{ and } N_{FR} < L_2$$

Transition:

$$\lambda_L \geq 0.01 \text{ and } L_2 < N_{FR} \leq L_3$$

Intermittent:

$$0.01 \leq \lambda_L < 0.4 \text{ and } L_3 < N_{FR} \leq L_1$$

or

$$\lambda_L \geq 0.4 \text{ and } L_3 < N_{FR} \leq L_4$$

Distributed:

$$\lambda_L < 0.4 \text{ and } N_{FR} \geq L_1$$

$$\lambda_L \geq 0.4 \text{ and } N_{FR} > L_4$$

In order to calculate the two phase density, the holdup H_L (φ), which exists at the same conditions in a horizontal pipe is calculated as follows:

$$H_L\ (O) = \frac{a\ \lambda_L^b}{N_{FR}^C}$$

where a, b and c are determined for each flow pattern from the following table:

Flow Pattern	a	b	c
Segregated	0.980	0.4846	0.0868
Intermittent	0.845	0.5351	0.0173
Distributed	1.065	0.5824	0.0609

with the restriction that $H_L(O) \geq \lambda_L$.

The factor for correcting the holdup for the effect of pipe inclination is given by:

$$\psi = 1 + C\ [\ \sin\ (1.8\ \phi) - 0.333\ \sin^3\ (1.8\ \phi)]$$

where ϕ is the actual angle of the pipe from horizontal.

$$C = (1 - \lambda_L)\ \ln\ (d\ \lambda_L^e\ N_{LV}^f\ N_{FR}^g)$$

where d, e, f and g are determined for each flow pattern from the following table:

Flow Pattern	d	e	f	g
Segregated	0.011	-3.768	3.539	-1.614
Intermittent	2.960	0.305	-0.4473	0.0978
Distributed	No correction	$C = 0$	$\psi = 1$	$H_L \neq f(\varphi)$
All flow patterns downhill	4.70	-0.3692	0.1244	-0.5056

with the restriction that $C \geq 0$.

The two phase density is $H_L(\varphi) = H_L(0)\ \psi$

The friction factor is calculated as follows:

$$\left(\frac{dP}{dz}\right)_f = \frac{f_{t.p}\ \rho_n\ V_m^2}{2\ g_c\ d}$$

where, $\rho_m = \rho_L\ \lambda_L + \rho_g\ \lambda_g$

$$f_{t.p} = fn\ \frac{f_{t.p}}{f_n}$$ is the two-phase friction factor.

The no slip friction factor for smooth pipe is given by:

$$f_n = \left[\,2\ \log\left(\frac{R_e}{4.5223\ \log R_e - 3.8215}\right)\right]^{-2}$$

where

$$R_e = \frac{\rho_m\ V_m\ d}{\mu}$$

$$\mu = \mu_L\ \lambda + \mu_g\ (1 - \lambda)$$

and for rough pipe the friction factor is determined from the Moody diagram (Fig. 2.4).

The ratio of the two-phase to no slip friction factor is calculated from:

$$\frac{f_{t.p}}{f_n} = e^S$$

where

$$S = \frac{\ln(y)}{-0.0523 + 3.182 \ln(y) - 0.8725 [\ln(y)]^2 + 0.01853 [\ln(y)]^4}$$

$$y = \frac{\lambda_L}{[H_L(\varphi)]^2}$$

If $1 < y < 1.2$, then $S = \ln(2.2y - 1.2)$

The accelerational pressure drop gradient is given as:

$$\left(\frac{dP}{dz}\right)_{acc} = \frac{\rho_s V_m V_{sg}}{g_c P} \frac{dP}{dz}$$

where the acceleration term is defined as:

$$E_k = \frac{\rho_s V_m V_{sg}}{g_c P}$$

The total pressure gradient can be calculated as:

$$\left(\frac{dP}{dz}\right)_{TOT} = \frac{\left(\frac{dP}{dz}\right)_{elv} + \left(\frac{dP}{dz}\right)_{f}}{1 - E_k}$$

where

$$\left(\frac{dP}{dz}\right)_{elv} = \frac{g}{g_c} \rho_s$$

(6) **Kabir and Hasan Correlation [30] (1986)**

Kabir and Hasan developed a correlation which was based on theoretical models for predicting pressure drop. Model development consisted of studying the hydrodynamic condition that gives rise to the various flow pattern transitions. The method for estimating pressure drop in each flow regime was then developed. The contribution of the static head, the frictional loss, and the kinetic energy were examined in developing the equations for pressure gradient determination.

Laboratory data were tested against the correlation. The agreement between the theory and experimental works was claimed to be excellent. Four flow patterns were identified (bubble, slug, churn and annular), With three flow transitions (bubble-slug flow transition, slug-churn flow transition, and churn-annular flow transition) defined as follows:

The bubble flow transition criteria:

$$V_{sg} < [0.429\ V_{sL} + 0.357\ V_t] \quad \text{and} \quad V_t < V_{tT}$$

or

$$E_g < 0.52$$

and

$$V_m^{1.12} > 4.68\ (d)^{.48}\ [g\ (\rho_L - \rho_g)/\sigma]^{.5}\ (\sigma/\rho_L)^{.6}\ (\frac{\rho_m}{\mu_L})^{0.08}$$

where

$$E_g = \frac{V_{sg}}{(C_o\ V_m + V_t)}$$

$$C_o = 1.2$$

$$V_t = 1.50\ [\frac{g\ \sigma\ (\rho_L - \rho_g)}{\rho_L^2}]^{1/4}$$

The flowing mixture density is calculated as follows:

$$\rho_m = (1 - E_g)\ \rho_L + E_g\ \rho_g$$

$$(\frac{\Delta P}{\Delta Z})_{st} = \frac{\rho_m}{g_c} \cdot g$$

The friction pressure drop is calculated using Chen [10] correlation:

$$(\frac{dP}{dz})_f = \frac{2\ f\ V_m^2\ \rho_m}{g_c\ d}$$

$$\frac{1}{(f)^{.5}} = 4\ \log\ [\frac{\frac{\varepsilon}{d}}{3.7065} - \frac{5.0452\ \log\ A}{R_e}]$$

$$A = \frac{(\frac{\varepsilon}{d})^{1.1098}}{2.8257} + (\frac{7.149}{R_e})^{0.8981}$$

$$R_e = \frac{1488\ DV\ \rho_m}{\mu}$$

The slug flow transition criteria is:

$$V_{sg} > (0.429\ V_{sL} + 0.357\ V_t)$$

and

$$V_{sg}^2\ \rho_g < |17.1\ \log\ (\rho_L\ V_{sL}^2) - 23.2|\ , \quad \text{for} \quad \rho_L\ V_{sL}^2 > 50$$

or

$$V_{sg}^2 \, \rho_g < 0.00673 \, (\rho_L \, V_{sL}^2)^{1.7} \quad \text{for} \quad \rho_L \, V_{sL}^2 > 50$$

The flowing mixture density is calculated as follows:

$$\rho_m = (1 - E_g) \, \rho_L + E_g \, \rho_g$$

$$E_g = \frac{V_{sg}}{C_1 \, V_m + V_{tT}}$$

$$C = 1.2$$

$$V_{tT} = 0.345 \, \left(\frac{gd \, (\rho_L - \rho_g)}{\rho_L}\right)^{1/2}$$

$$\left(\frac{\Delta P}{\Delta Z}\right)_{st} = \frac{\rho_m}{g_c} \cdot g$$

The friction pressure drop:

$$\left(\frac{\Delta P}{\Delta Z}\right)_f = \frac{2 \, f \, V_m^2 \, \rho_L \, (1 - E_g)}{g_c \, d}$$

where the friction factor is calculated as in the bubble flow.

The churn flow transition criteria is:

$$V_{sg} < 3.1 \, [\, \sigma \, g \, (\rho_L - \rho_g)/\rho_g^2]^{0.25}$$

and

$$V_{sg}^2 \rho_g > [17.1 \log (\rho_L V_{sl}^2) - 23.2] \quad \text{for} \quad \rho_L V_{sl}^2 > 50$$

or

$$V_{sg}^2 \rho_g > 0.00673 (\rho_L V_{sL}^2)^{1.7} \quad \text{for} \quad \rho_L V_{sL}^2 < 50$$

The flowing mixture density is calculated as in the slug flow except that the constant C_1 was used as 1.0 instead of 1.2. Also, the frictional pressure drop is the same as in the slug flow.

The annular flow transition criteria is:

$$V_{sg} > 3.1 [\sigma g (\rho_L - \rho_g)/\rho_g^2]^{0.25}$$

The flowing mixture density is calculated as follows:

$$E_g = \frac{V_{sg}}{V_{sg} + E V_{sL}}$$

where

$$E = 0.0055 [(V_{sg})_c \times 10^4]^{2.86}, \quad \text{for} \quad (V_{sg})_c \times 10^4 \leq 4$$

$$E = 0.857 \log [(V_{sg})_c \times 10^4]^{-0.2}, \quad \text{for} \quad (V_{sg})_c \times 10^4 > 4$$

where

$$(V_{sg})_c = \frac{V_{sg}\ \mu_g\ (\frac{\rho_g}{\rho_L})^{0.5}}{\sigma}$$

The friction pressure drop is calculated as:

$$(\frac{\Delta P}{\Delta Z})_f = \frac{2\ f_c\ \rho_c\ (\frac{V_{sg}}{E_g})^2}{g_c\ d}$$

where

$$f_c = 0.079\ \frac{[1 + 75\ (1 - E_g)]}{R_e^{0.25}}$$

$$E_g = (1 + X^{0.8})^{0.378}$$

$$X = (\frac{1 - x}{x})^{0.9}\ (\frac{\rho_g}{\rho_L})^{0.5}\ (\frac{\mu_L}{\mu_g})^{0.1}$$

$$\rho_c = \frac{V_{sg}\ \rho_g + E\ V_{sL}\ \rho_L}{V_{sg} + E\ V_{sL}}$$

The acceleration pressure gradient equation is:

$$\left(\frac{\Delta P}{\Delta Z}\right)_{acc} = \frac{1}{g_c} \frac{[g\ \rho_c + (2f_c\ \rho_C\ V_g^2/d)]}{[1 - (\rho_c\ V_g^2/P\ g_c)]}$$

The total pressure gradient equation is:

$$\left(\frac{dP}{dz}\right)_{TOT} = \left(\frac{dP}{dz}\right)_{st} + \left(\frac{dP}{dz}\right)_{f} + \left(\frac{dP}{dz}\right)_{acc}$$

2.2 Review of Comparison Studies

Several studies have been performed to evaluate multiphase flow pressure drop correlations. Orkiszewski [39] performed a comparative study of existing correlations and developed a correlation based on 148 well cases. His correlation was found better than Hagedoon and Brown [28], and Duns and Ros [17] methods.

A later study by Espanol [19] in 1968 on 44 wells confirmed the Orkiszewski conclusions. The method of Orkiszewski was found to be the most accurate for engineering design usage and was the only correlation which could evaluate a three phase flow condition when water was simultaneously being produced with the gas-oil mixture.

Camacho [8] in 1970 tested five correlations against data from 111 wells with high gas-liquid ratios (GLR). None of the wells was in mist flow as defined by the correlations of Duns and Ros [17] or Orkiszewski [39], although the GLR reached a value of 787,000

SCF/STB. Most of the data were for gas wells making slight amounts of water. He concluded that no method was sufficiently accurate to cover all ranges of GLR. The Fancher and Brown [20] correlation gave the best result followed by Poettmann's [40] correlation. The Dun and Ros [17], and Orkiszewski [39] methods performed better when forced into mist flow for GLR > 10,000 SCF/STB.

A study by Messulam [36] in 1970 involved 434 wells to test available correlations. He used published data from Bexendell [7], Fancher and Brown [20], Hagedorn and Brown [28], Orkiszewski [39], Poettman and Carpenter [40] as well as unpublished data. He concluded that Hagedorn and Brown correlation was the most accurate followed by Orkiszewski's correlation. the Dun and Ros [17] correlation was the least accurate. None of the correlations was accurate for all flow conditions.

Lawson and Brill [33] performed a study on 726 well tests. They used the Poettmenn and Carpenter [40], Baxendell and Thomas [7], Fancher and Brown [20], Duns and Ros [17], Hagedorn and Brown [28] and Orkiszewski [39] methods. None of the correlations was superiors for all ranges of data. The Hagedorn and Brown method performed best followed by Orkiszewski, and Fancher and Brown correlations.

Vohra et al. [48] evaluated new pressure loss prediction methods for the same data used by Lawson and Brill [33]. The results of their study showed that the Aziz et al. [1] method gave the best performance followed by the Beggs and Brill [4] and the Chierici et al. [11] correlations.

Aziz et al. [1] compared their correlation against Orkiszewski, Hagedorn and Brown, and Duns and Ros correlations. 48 well tests were used for the comparison. They concluded that the absolute error from their correlation is about the same as for the Orkiszewski correlation.

Chierici et al. [11] used 31 well tests to verify their correlation. They calibrated the PVT correlations against experimental PVT data. The statistical results reported were very good. Vohra et al. [48] tried to match the Chierici et al. results to verify their computer program, but their average percent errors and standard deviations were higher than that given by Chierici et al. They had to delete some well cases from the Chierici et al. data to get the same statistical results. In a study performed by Ibe [29] in 1979, he concluded that Hagedorn and Brown performed best for 891 well tests he used. This is in agreement with Lawson and Brill [33], and the Vohra et al.

Kabir et al. [30] in 1986 used 115 tests to evaluate several correlations. They concluded that their correlation performs as well as the Aziz et al. and Orkiszewski correlations when the flow is predominantly in the bubbly and slug flow regimes. They also claimed that in the churn and annular flow regimes, their correlation is superior to the existing models.

CHAPTER 3

RESULTS AND DISCUSSION

Chapter 3
RESULTS AND DISCUSSION

In this chapter, the field data used in the analysis are presented and discussed. Then, the computer program prepared for predicting the multiphase-flow pressure drop with the various correlations is presented. The method used in the analysis and evaluation of the correlations is then discussed. Each of the vertical multiphase flow correlations is then evaluated using the measured field data. Finally, a comparison of all correlations is made, and the best correlation for predicting the present data is determined.

3.1 Field Data

Data from 414 well tests from five different Saudi Arabian fields were used in the present study. Table 3.1 gives the maximum and minimum values for the various variables covered by the present data.

All data reported were obtained from well-tests files. The tubing description for each well was obtained from the completion reports. Flow rates, pressures, and temperatures were all obtained under steady state conditions.

Table 3.1: Range of Variables for the Present Data

	Minimum	Maximum
Total Production Rate, STB/Day	280	24,900
Oil Production Rate, STB/Day	280	23,200
Gas Production Rate, MSCF/Day	3.374	20,200
Water Production Rate, STB/Day	1	7,705
Gas-Liquid Ratio, SCF/STB	6	927
Measured (Vertical) depth, ft.	4,550	8,580
Inside Diameter, in.	2.375	6.366
Measured Bottom Hole Pressure, psia	1,115	3,105
Measured Well Head Pressure, psia	10	800
Well Head Temperature, v¢vF	76	160
Bottom Hole Temperature, v¢vF	157	215

Pressures were measured at the wellhead and the bottomhole at a known depth. The wellhead pressures were measured by calibrated pressure gauges or by dead-weight testers. The bottomhole pressures were measured using Amerada recorders. Normally, more than one pressure recorder spaced about 6 feet apart were used to measure the bottomhole pressure. The readings from the recorders were first corrected to a certain depth, and then averaged to obtain a value for the bottomhole pressure. The flowing bottomhole temperature was measured in a similar manner to the flowing bottomhole pressure. The flow rates of oil, water and gas were measured at the separator pressure and temperature, and were then corrected to standard conditions.

The data used in the present study are tabulated in Appendix B, Table B-1.

3.2 Computer Program

A computer program was developed for predicting pressure drop according to the six vertical multiphase flow correlations evaluated in this study. A listing of the program is given in Appendix B.

Figure 3.1 shows a simplified algorithm of the computational procedure used in this program. It involves an iterative procedure for calculating depth increments corresponding to specified values of

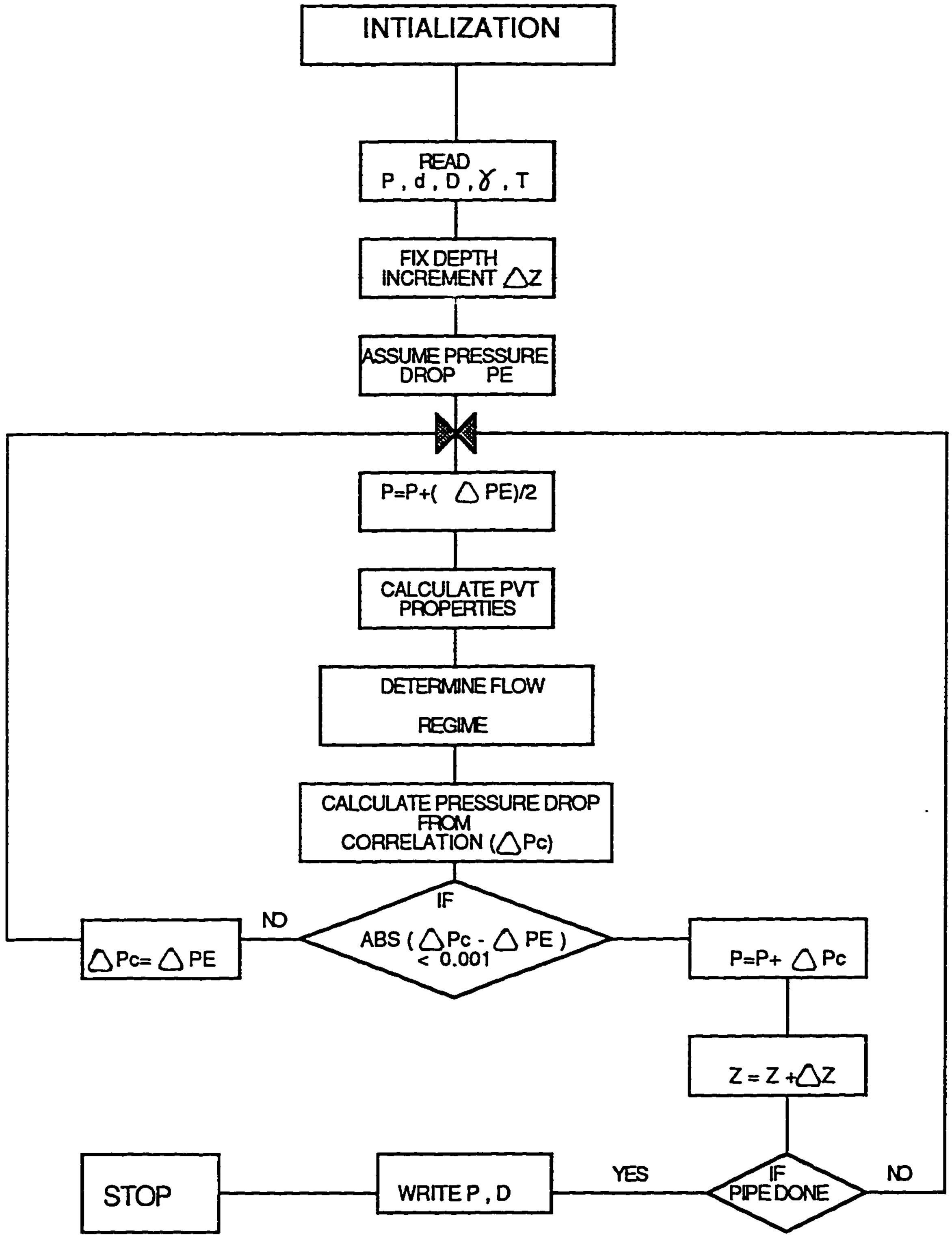


Fig. 3.1: Algorithm for Pressure Traverse Calculations.

pressure drop. The calculations require the determination of the temperature, fluid properties, hold up, flow pattern and friction factor at each increment of depth. A linear interpolation between the wellhead and bottomhole flowing temperatures was used to determine the temperature at any depth. The correlations used for fluid properties determinations are listed in Table 3.2. The holdup, flow pattern and friction factor correlations varied from one multiphase flow correlation to another. Separate subroutines were prepared for determining thse parameters for each multiphase flow correlation.

3.3 Method of Analysis

Each of the six vertical multiphase flow correlations studied is evaluated separately with regard to its ability and accuracy of predicting the pressure data. All six correlations are then compared to determine and recommend the best correlation for predicting the present data.

For each correlation, the predicted (calculated) pressures are cross-plotted against the measured (observed) pressures along with the 45° straight line. The cross-plot helps in illustrating, in general, the accuracy of the correlation as well as the general trends of over- or under-predictions. A statistical analysis of the predictions of the correlation is then performed using the following statistical parameters.

Table 3.2: PVT Correlations

PVT Property	Correlations
Oil Formation Volume Factor	Frick [22]
Solution Gas-Oil Ratio	Standing [43]
Oil Viscosity:	
Dead Oil	Beggs and Robinson [5]
Live Oil	Beggs and Robinson [5]
Gas Viscosity	Lee et al. [34]
Gas Deviation Factor (Z-factor)	Standing-Katz [31]

(a) **Percent Relative Error (e)**

It is the relative deviation of a calculated value from a corresponding measured value, and is defined by:

$$e = \left(\frac{P_m - P_c}{P_m} \times 100\right) \qquad (3.1)$$

where

P_m = measured pressure

P_c = calculated pressure

(b) **Average Absolute Percent Relative Error (AAPE)**

It is a measure of the relative absolute deviation of the calculated value from the measured value, i.e.:

$$AAPE = \frac{1}{n} \sum_{i=1}^{n} |e_i| \qquad (3.2)$$

where n is the number of data points.

A lower value of AAPE indicates a better correlation.

(c) **Standard Deviation (SD)**

It is a measure of the dispersion, or scatter of the predictions, and is defined by the following expression:

$$SD^2 = \frac{1}{n-1} \sum (e_i - APE) \qquad (3.3)$$

where APE is the average percent relative error.

A lower value of SD means a lesser degree of scatter, and hence, a better correlation.

(d) **Coefficient of Variance (CV)**

It is a measure of variation of all the data points under consideration:

$$CV = \frac{SD}{\frac{1}{n} \sum_{i=1}^{n} P_m} * 100 \qquad (3.4)$$

(e) **Correlation Coefficient (r)**

The correlation coefficient (r) represents the degree of success in reducing the standard deviation of a correlation. It is obtained from the following expression:

$$r^2 = 1 - \frac{\sum_{i=1}^{n} (P_c - P_m)_i^2}{\sum_{i=1}^{n} (P_m - P_a)_i^2} \tag{3.5}$$

where

$$P_a = \frac{1}{n} \sum_{i=1}^{n} (P_m)_i$$

The value of the correlation coefficient lies between zero and one. A value of one indicates a perfect correlation while a value of zero implies no correlation at all among the variables.

In addition to the above statistical parameters, a plot of the error distribution for each correlation is also prepared. In such a plot, the frequency of the percent relative error is plotted against the percent relative error using a histogram-type of plot. The normal distribution curve is also superimposed on the histogram. The accuracy and degrees of overprediction or underprediction are judged by comparing the normal distribution curve to the histogram.

Finally, a comparison of all six correlations is presented in Section 3.5.5. This is done by comparing average absolute percent relative errors of the various correlations. For this purpose, the data were divided into subgroups according to the tubing size, the water cut, the gas-oil ratio and the total liquid rate.

3.4 Evaluation of the Correlations

The results of the bottom home pressure predictions for each of the evaluated correlations are discussed in separate subsections below. First, the results are presented in cross-plot forms. Then, the error contribution is presented and discussed, and finally, the correlation is analyzed using the various statistical parameters discussed earlier.

3.4.1 Hagedorn and Brown Correlation [28]

The calculated and the observed bottom hole pressures are cross-plotted in Figs. 3.2, 3.3 and 3.4 for all data. The figures respectively present the data with the tubing size as a parameter, with the water cut as a parameter and with the gas-liquid ratio as a parameter. Investigation of these figures shows that with the exception of a few data points, the correlation provides, in general, good pressure prediction for all tubing sizes. It shows that the correlation predicts the pressure better for the smaller tubing sizes than for the larger ones. The correlation tends to underpredict the pressure for the zero water cut. However, it tends to predict the pressure better in wells with high water cuts. Furthermore, the correlation tends to predict the pressure drop better in wells with low gas-liquid ratio than in wells with high gas-liquid ratio.

Figure 3.5 shows the error distribution histogram and the normal

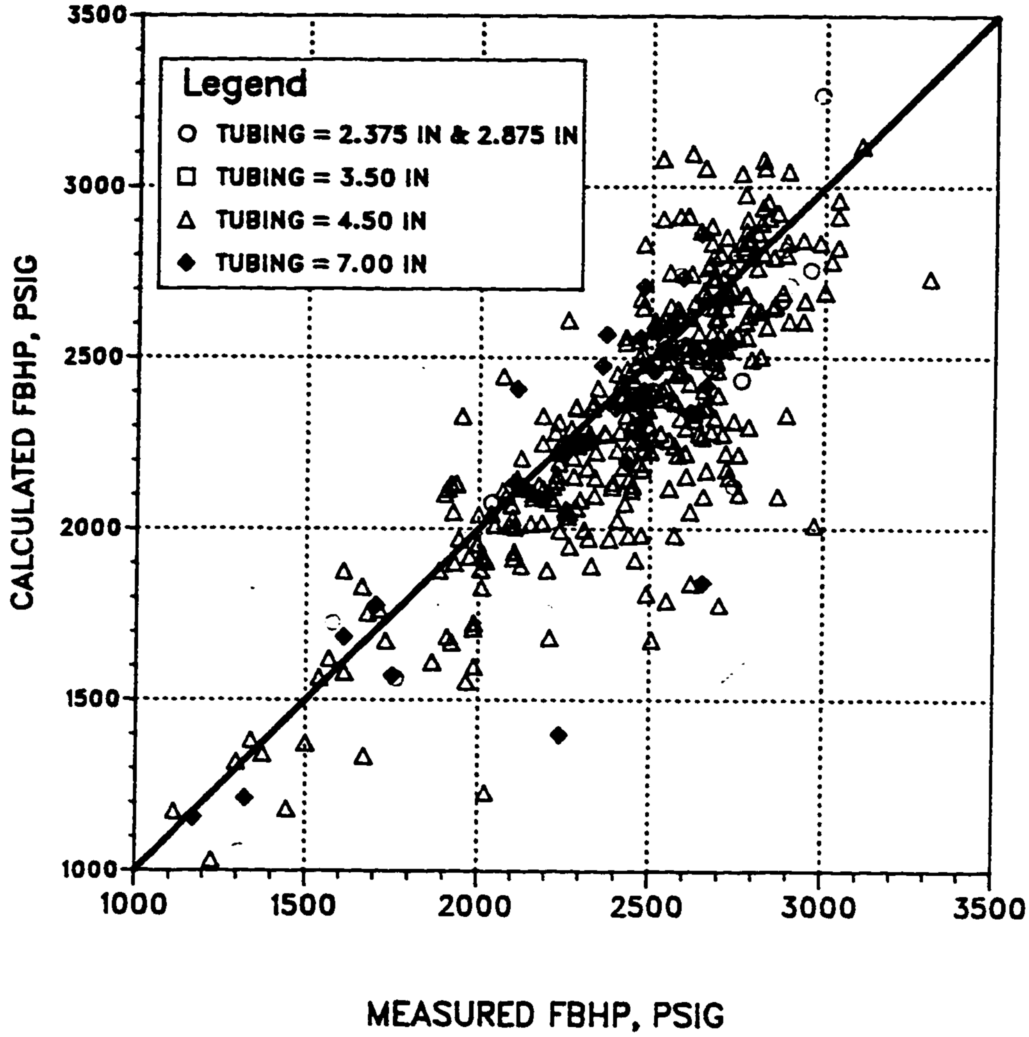


Fig. 3.2: Observed vs. Calculated Pressure using Hagedorn and Brown Correlation with Tubing Size as a Parameter.

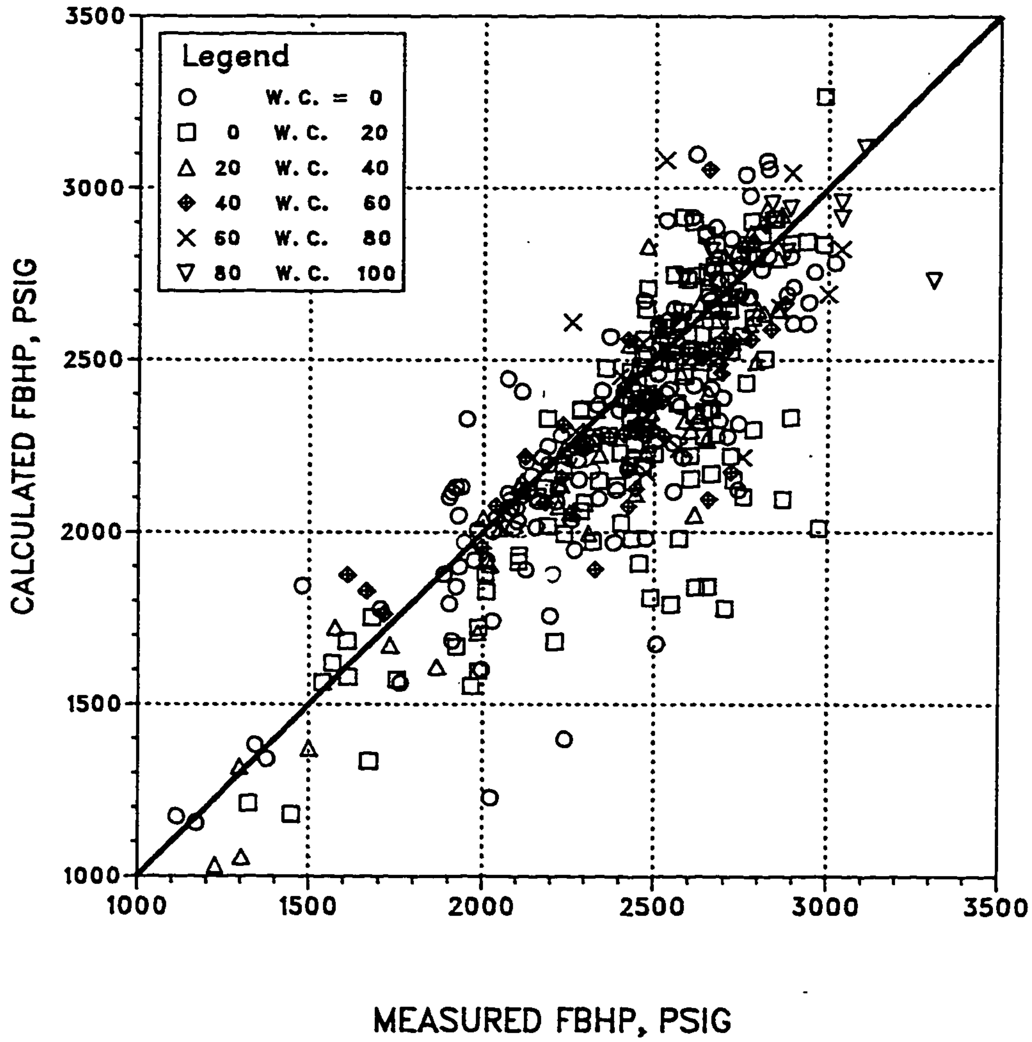


Fig. 3.3: Observed vs. Calculated Pressure using Hagedorn and Brown Correlation with Water Cut as a Parameter.

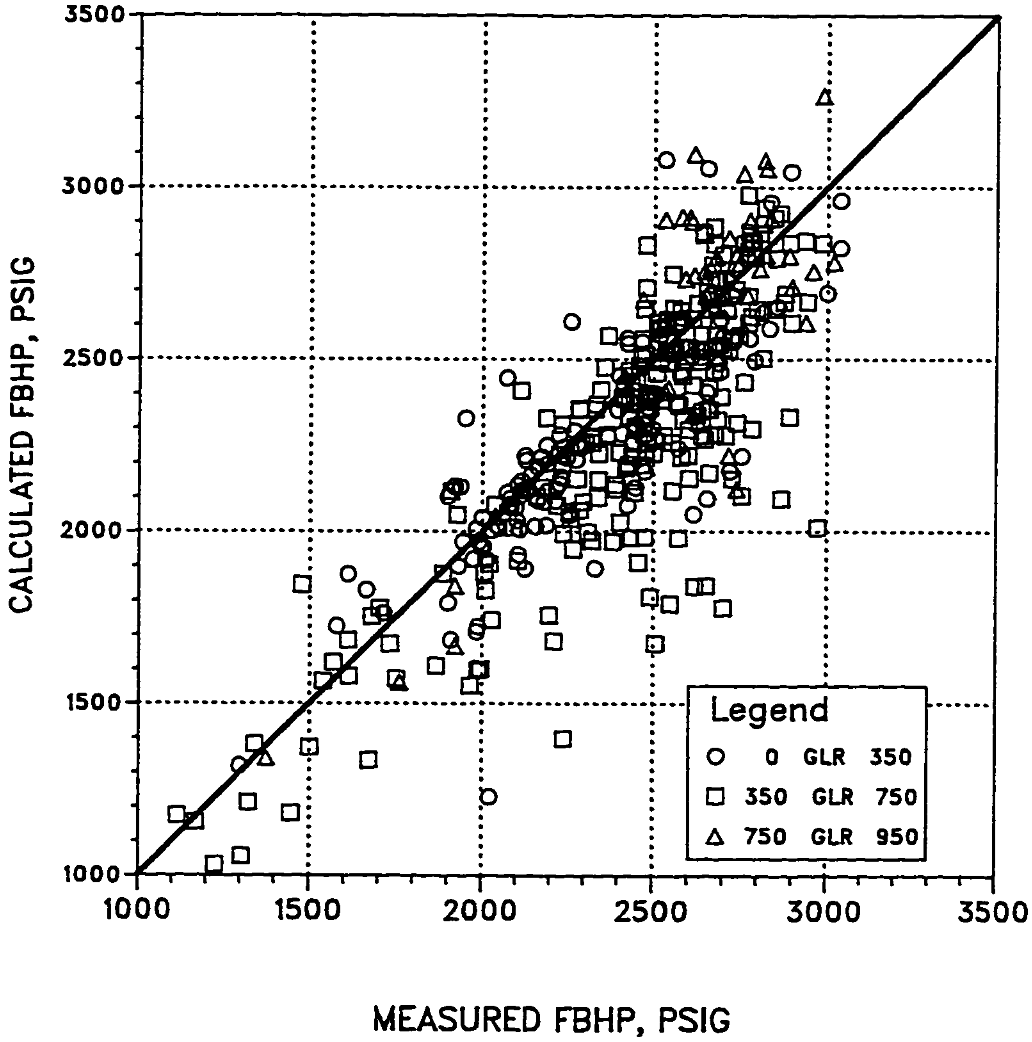
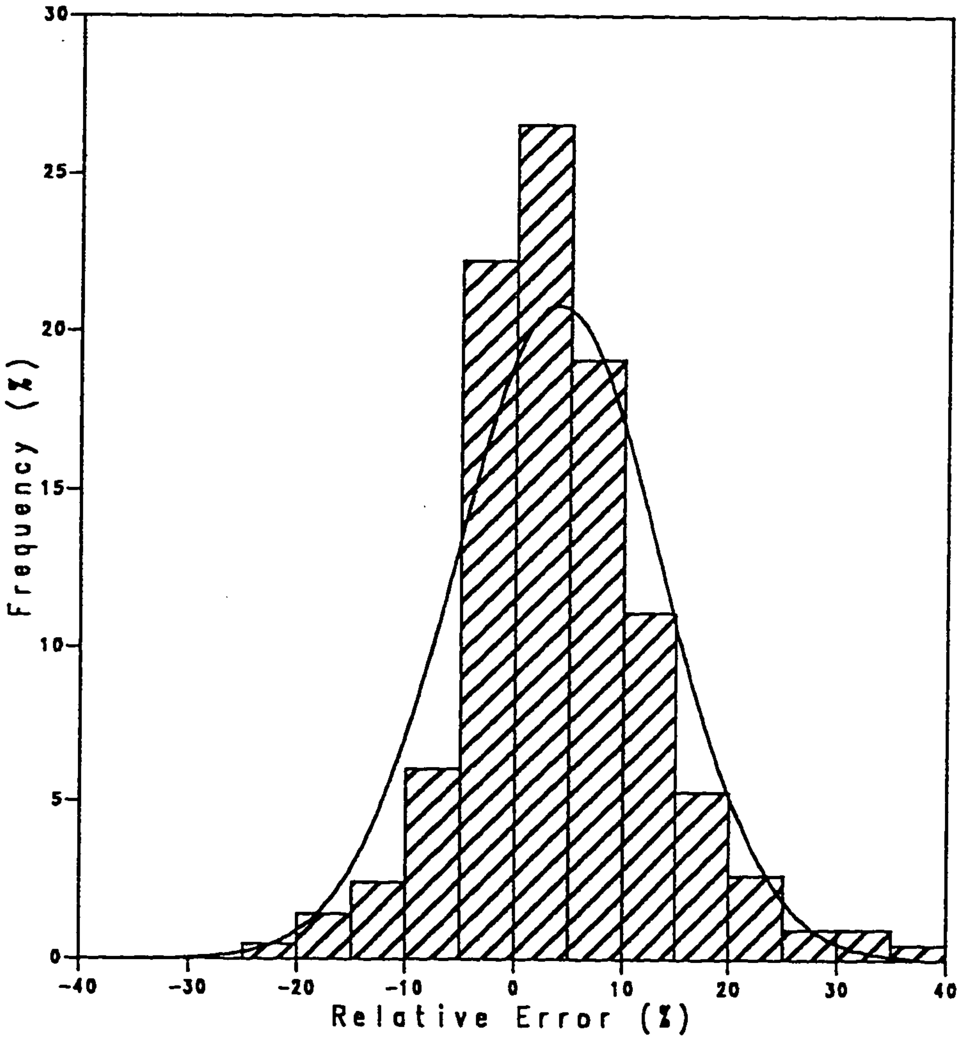


Fig. 3.4: Observed vs. Calculated Pressure using Hagedorn and Brown Correlation with Gas-Liquid Ratio as a Parameter.

distribution curve for this correlation. The errors are normally distributed with a mean approximately equals to 3%, indicating a good correlation.

Tables 3.3, 3.4, 3.5 and 3.6 summarize the statistical analysis of the data for different tubing sizes. For the 2.375 in. and 2.875 in. tubings, the accuracy of the correlation is better in wells with high water cuts. Only 58% of the data point with zero water cut lie within ± 10% error, while 87% of the data points with water cuts higher than 20% lie within ± 10% error. The average absolute percent error, the coefficient of variance and the correlation coefficient are 10.1, 13.3 and 0.61 respectively for zero water cut, while they are 6.77, 6.89 and 0.96 respectively for wells with water cut greater than 20%. The correlation tends to predict the pressure better in wells with low gas-liquid ratios. 100% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 10% error, while only 57% of the data points with gas-liquid ratio more than 750 SCF/STB lie within ± 10% error.

For the 3.5 in. tubing, the correlation provides reasonably good predictions for the 10 data points available. For the 4.5 in. tubing size, the correlation provides better pressure predictions in wells with high water cuts. 82% of the data points with water cuts greater than 80% lie within ± 5% error, while only 50% of the data points with zero water cut lie within ± 5% error. It is apparent that the presssure prediction is not sensitive to the gas-liquid ratio.



3.5 Error Distribution for Hagedorn and Brown Correlation.

Table 3.3: Statistical Analysis Results for Hagedorn and Brown Correlation, 2.375 in. and 2.875 in. Tubings

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	10.1	340	13.3	0.61	7	29%	58%	71%			100%
0 < Watercut < 20%	5.76	214	7.86	0	8	50%	75%	100%			
20% < Watercut < 100%	6.77	161	6.98	0.96	8	50%	87%	100%			
0 < GLR < 350	5.20	136	5.59	0.96	5	60%	100%				
350 < GLR < 750	6.90	215	8.70	0.88	11	55%	73%	82%	91%	100%	
750 < GLR < 950	9.85	332	12.4	0.62	7	14%	57%	86%		100%	
All Data	7.43	233	9.23	0.85	23	44%	74%	87%	91%	100%	

Table 3.4: Statistical Analysis Results for Hagedorn and Brown Correlation, 3.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
All Data	9.15	234	10.6	0.81	10	50%	70%	80%	90%	100%	

Table 3.5: Statistical Analysis Results for Hagedorn and Brown Correlation, 4.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	7.13	256	10.9	0.68	117	50%	73%	91%	98%		100%
0 < Watercut < 20%	8.59	300	12.2	0.22	114	47%	68%	80%	89%	95%	100%
20% < Watercut < 40%	6.20	188	7.80	0.87	56	54%	79%	98%	99%	100%	
40% < Watercut < 60%	7.27	227	9.28	0.65	37	43%	81%	87%	98%	100%	
60% < Watercut < 80%	8.21	275	10.6	0.47	17	35%	64%	82%	94%	100%	
80% < Watercut < 100%	4.00	202	6.98	0.23	11	82%	91%		100%		
0 < GLR < 350	6.31	212	9.02	0.79	126	57%	79%	90%	97%	99%	100%
350 < GLR < 750	8.28	289	11.7	0.48	194	43%	69%	84%	92%	96%	100%
750 < GLR < 950	6.59	223	8.52	0.71	32	50%	72%	94%	100%		
All Data	7.42	257	10.5	0.66	352	49%	73%	87%	94%	97%	100%

Table 3.6: Statistical Analysis Results for Hagedorn and Brown Correlation, 7 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	7.45	292	13.2	0.70	12	58%	83%	91%			100%
0 < Watercut < 100%	7.05	250	10.9	0.77	17	53%	82%	94%			100%
0 < GLR < 350	1.96	56.9	2.51	0.94	6	100%					
350 < GLR < 950	8.59	296	13.0	0.73	23	43%	78%	91%			100%
All Data	7.22	263	11.6	0.74	29	55%	83%	93%			100%

For the 7 in. tubing size, the correlation predicts the pressure better in wells with high water cuts. The coefficient of variance and the correlation coefficient are 13.2 and 0.70 respectively for wells with zero water cut, while they are 10.9 and 0.77 respectively for wells with water cuts ,higher than zero. The correlation predicts the pressure better in wells with low gas-liquid ratios. 100% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 5% error, while only 43% of the data points with gas-liquid ratio more than 350 SCF/STB lie within ± 5% error. The average absolute percent error, the coefficient of variance and the correlation coefficient are 1.96, 2.5 and 0.94 for wells with gas-liquid ratio less than 350 SCF/STB, while they are 5.59, 13.1 and 0.73 for wells with gas-liquid ratio more than 350 SCF/STB.

3.4.2 Aziz and Govier Correlation [1]

The calculated bottom hole pressures from Aziz and Govier correlation are cross-plotted against the observed bottom hole pressures in Figs. 3.6, 3.7 and 3.8. Figure 3.6 shows the cross-plot with the tubing size as a parameter, Fig. 3.7 shows the cross-plot with the water cut as a parameter and Fig. 3.8 shows the cross-plot with the gas-liquid ratio as a parameter.

Investigation of these figures shows that the correlation tends to underpredict the bottom hole pressures for all tubing sizes It also

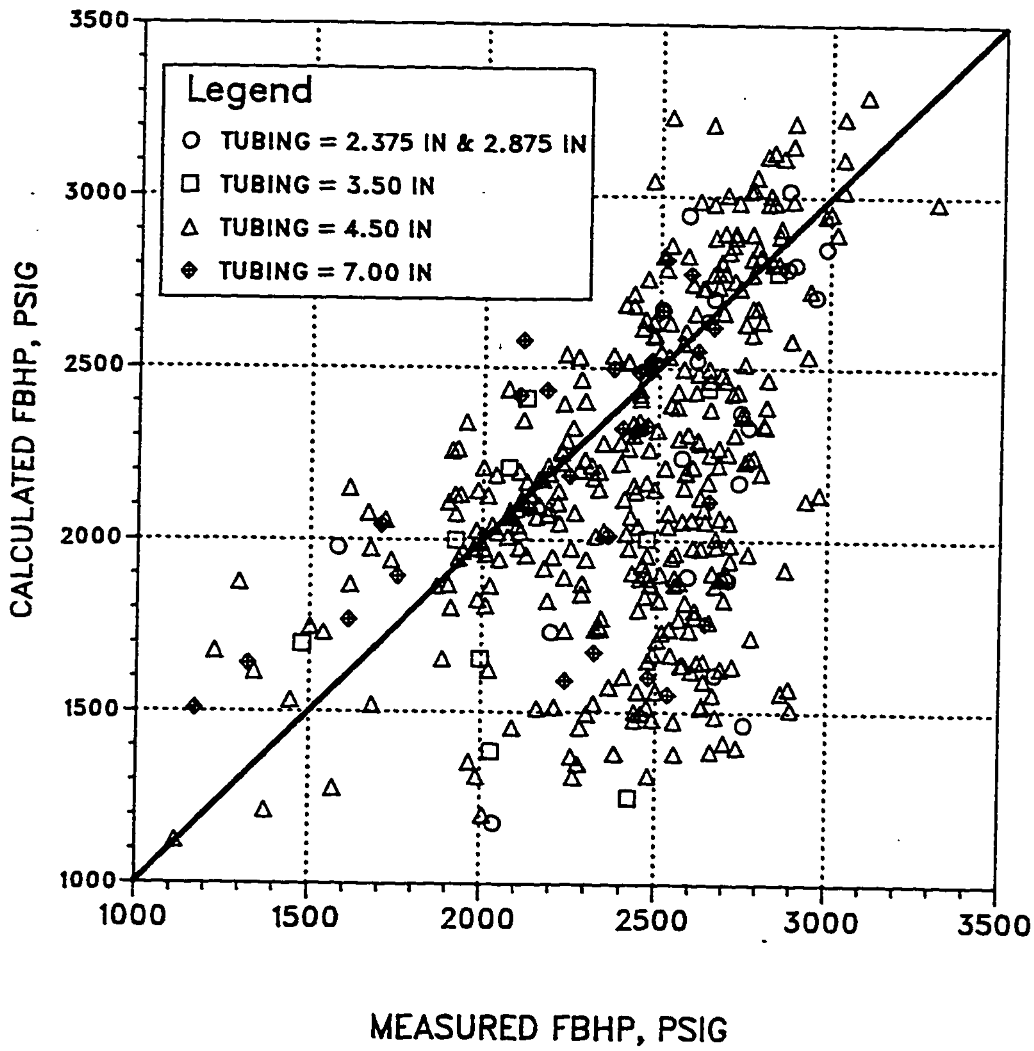


Fig. 3.6: Observed vs. Calculated Pressure using Aziz and Govier Correlation with Tubing Size as a Parameter.

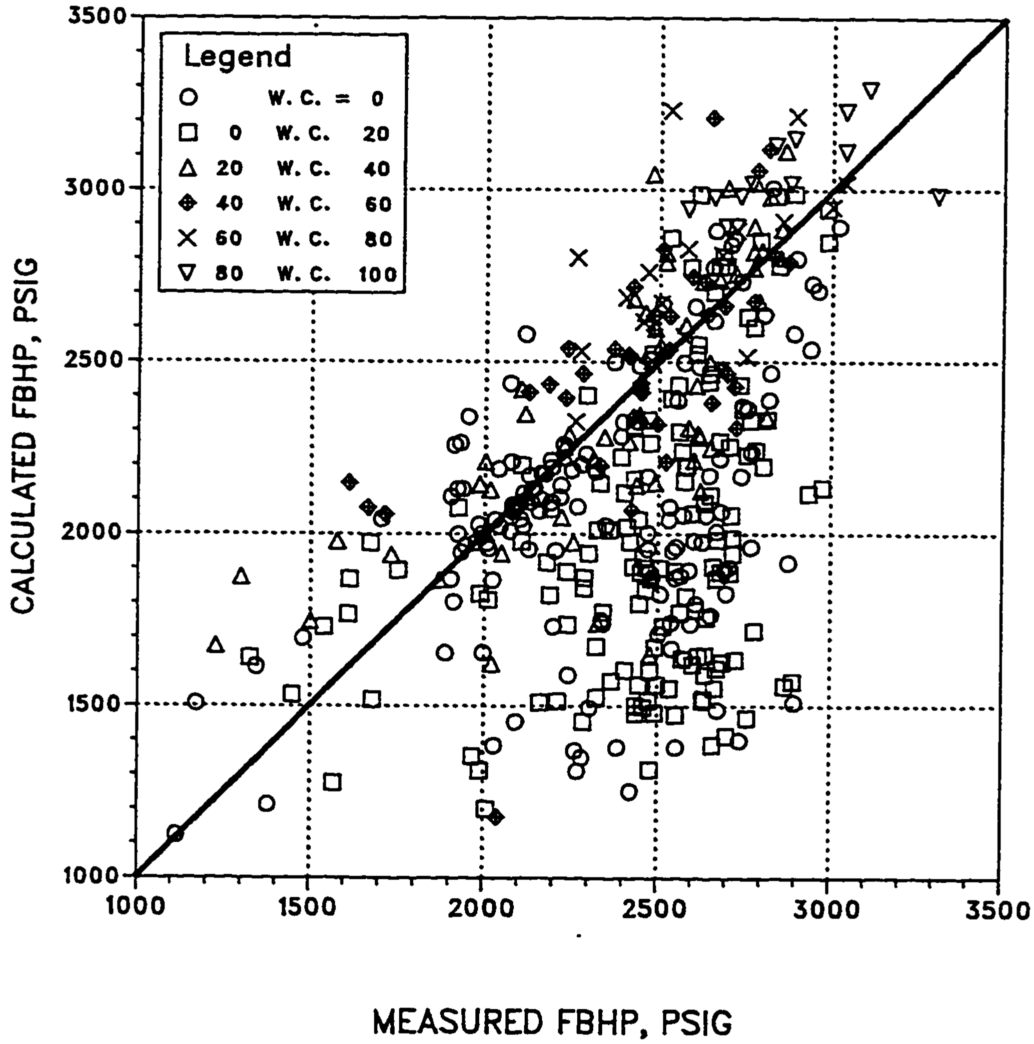


Fig. 3.7: Observed vs. Calculated Pressure using Aziz and Govier Correlation with Water Cut as a Parameter.

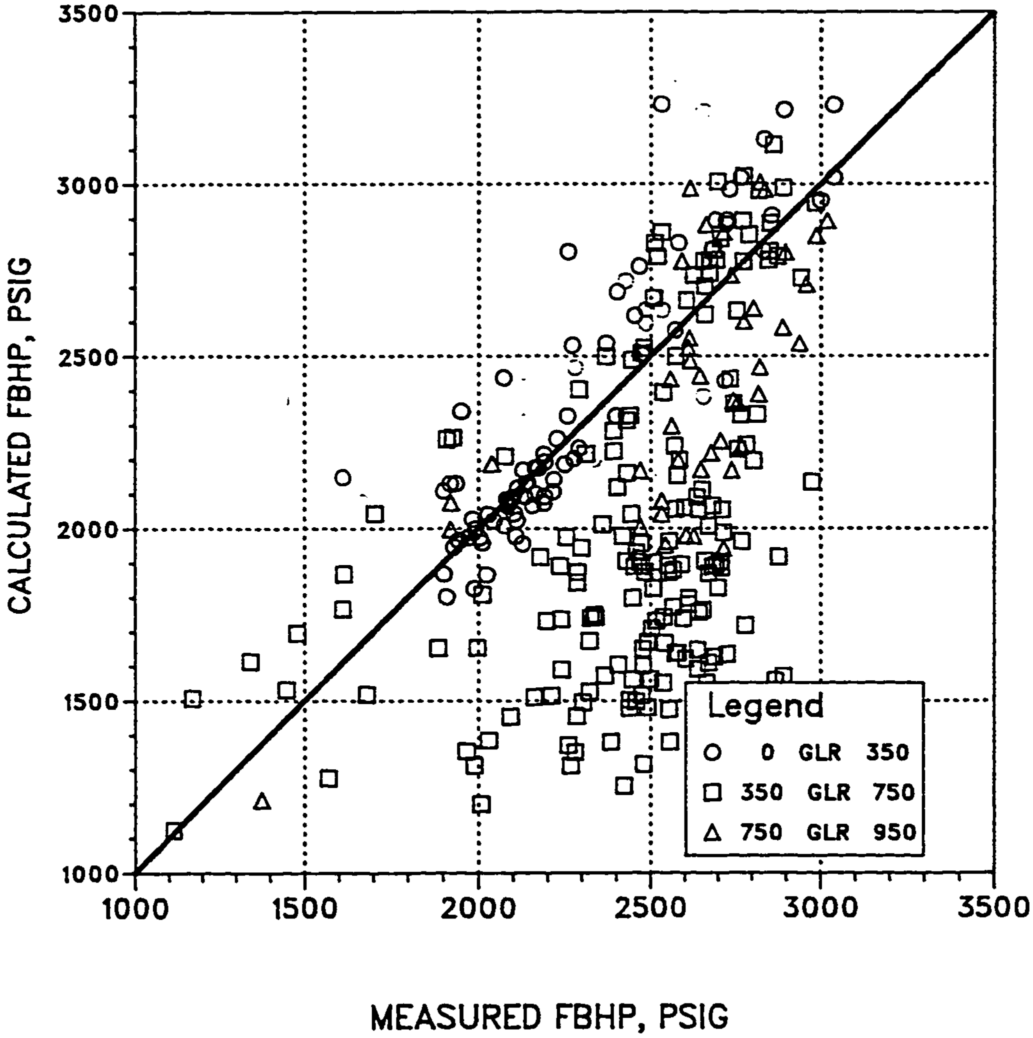


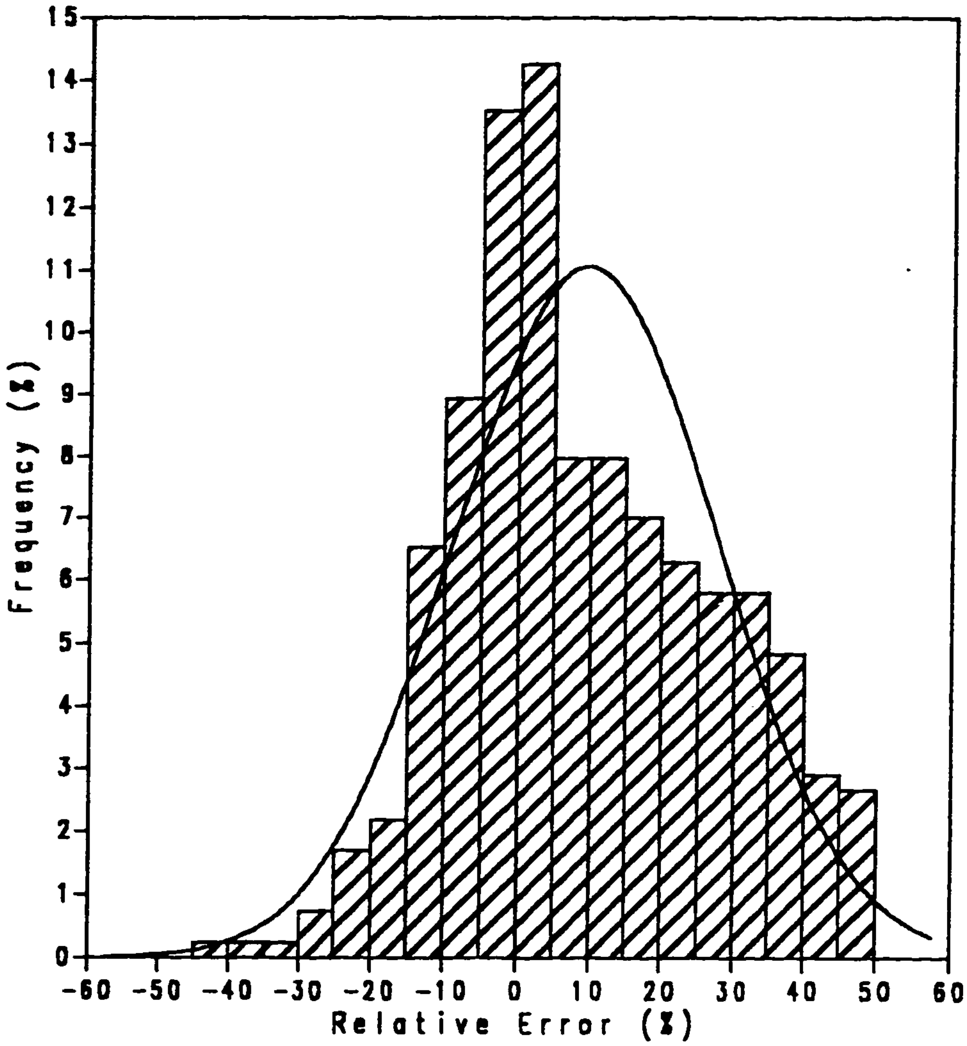
Fig. 3.8: Observed vs. Calculated Pressure using Aziz and Govier Correlation with Gas-Liquid Ratio as a Parameter.

shows that the correlation tends to underpredict the bottom hole pressure for low water cuts and tends to overpredict the bottom hole pressure for high water cuts. Further, the correlation underpredicts the bottom hole pressure as the gas-liquid ratio increases.

Figure 3.9 shows the error distribution histogram and the normal distribution curve for the correlation. It shows significant shift of the mean of the errors towards the positive side of the plot indicating that the pressure is underpredicted, with the mean approximately equals to 10%.

Tables 3.7, 3.8, 3.9 and 3.10 summarize the statistical analysis of the data for different tubing sizes. 40% of the 2.375 in. and 2.875 in. tubings data, 40% of the 3.5 in. tubing data, 45% of the 4.5 in. tubing data, and 52% of the 7 in. tubing data are predicted with ± 10% errors.

For the 2.375 in. and 2.875 in. tubing, the accuracy of the correlation is better in wells with high water cuts. Only 28% of the data points with zero water cut lie within ± 10% error, while 50% of the data points with water cuts higher than 20% lie within ± 10% error. The average absolute percent error, the coefficient of variance and the correlation coefficient are 23.7, 26.9 and zero respectively for zero water cut. While they are 18.3, 20.2 and 0.62 respectively for wells with water cut greater than 20%. There is no certain trend for the correlation with the gas-liquid ratio. 80% of the data points with gas-liquid ratio less than 350 SCF/STB, 27% of the data with gas-liquid



3.9 Error Distribution for Aziz and Govier Correlation.

Table 3.7: Statistical Analysis Results for Aziz and Govier Correlation, 2.375 in. and 2.875 in. Tubings

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	23.7	687	26.9	0	7	14%	28%	42%		71%	100%
0 < Watercut < 20%	19.4	738	27.1	0	8	37%		50%	63%		100%
20% < Watercut < 100%	18.3	465	20.2	0.62	8	37%	50%	62%			100%
0 < GLR < 350	10.2	291	12.0	0	5	40%	60%	80%			100%
350 < GLR < 750	26.4	752	30.5	0	11	18%		27%	36%	45%	100%
750 < GLR < 950	17.9	599	22.4	0	7	44%	58%	72%		86%	100%
All Data	20.3	609	24.1	0	23	31%	40%	53%	57%	65%	100%

Table 3.8: Statistical Analysis Results for Aziz and Govier Correlation, 3.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
All Data	16.5	507	23.0	0	10	20%	40%	60%	80%		100%

Table 3.9: Statistical Analysis Results for Aziz and Govier Correlation, 4.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	14.6	503	21.4	0	117	38%	48%	58%	67%	77%	100%
0 < Watercut < 20%	22.6	665	27.0	0	114	9%	21%	32%	47%	57%	100%
20 < Watercut < 40%	9.81	290	12.1	0.64	56	37%	57%	80%	89%	93%	100%
40 < Watercut < 60%	8.60	250	10.2	0.55	37	38%	65%	87%	92%	97%	100%
60 < Watercut < 80%	8.35	288	11.0	0.58	17	42%	65%	88%		94%	100%
80 < Watercut < 100%	8.03	253	8.75	0.70	11	9%	82%	100%			
0 < GLR < 350	6.72	210	8.97	0.79	126	50%	77%	92%	96%	98%	100%
350 < GLR < 750	21.3	636	25.7	0	194	16%	25%	38%	49%	60%	100%
750 < GLR < 950	12.7	385	14.7	0	32	12%	37%	65%	87%	97%	100%
All Data	15.3	501	20.5	0	352	28%	45%	59%	69%	77%	100%

Table 3.10: Statistical Analysis Results for Aziz and Govier Correlation, 7 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	10.3	290	13.1	0.70	12	50%	67%		75%	83%	100%
0 < Watercut < 100%	16.0	488	21.2	0	17	18%	43%	62%		80%	100%
0 < GLR < 350	7.66	229	10.1	0	6	50%		100%			
350 < GLR < 950	15.2	451	20.0	0	23	24%	48%	53%	58%	72%	100%
All Data	13.6	412	18.2	0	29	31%	52%	66%	69%	79%	100%

ratio between 350 and 750 SCF/STB, and 80% of the data with gas-liquid ratio higher than 750 SCF/STB, lie within ± 15% error.

For the 3.5 in. tubing data, the correlation providss poor predictions. Only 40% of the data points lie within ± 10% errors. The average absolute percent error, the coefficient of variance and the correlation coefficient are 16.5, 23.0 and zero respectively.

For the 4.5 in. tubing data, the accuracy of the correlation improves as the water cut increases. Only 48% of the data points with zero water cut lie within ± 10% error. While 82% of the data points with water cuts greater than 80% lie within ± 10%. The average absolute percent error, the coefficient of variance and the correlation coefficient are 14.6, 21.4 and zero respectively for zero water cut. While they are 8.03, 8.75 and 0.70 respectively for wells with water cut greater than 80%. There is no certain trend of the accuracy of the correlation with gas-liquid ratio. However, the correlation predicts the pressure better in wells with gas-liquid ratio less than 350 SCF/STB. 77% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 10% error, while only 37% of the data points with gas-liquid ratio more than 750 SCF/STB lie within ± 10% error. The average absolute percent error, the coefficient of variance and the correlation coefficient are 6.72, 8.97 and 0.79 respectively for gas-liquid ratio less than 350 SCF/STB. While they are 12.7, 14.7 and zero for gas-liquid ratio more than 750 SCF/STB.

For the 7 in. tubing, the accuracy of the correlation is better for zero percent water cut. 67% of the data points with zero percent water cut lie within ± 10% error. While 43% of the data points with water cut greater than zero lie within ± 10%. The average absolute percent error, the coefficient of variance and the correlation coefficient are 10.3, 13.1 and 0.70 respectively for zero percent water cut. While they are 16.0, 21.2, and zero respectively for water cut greater than zero. The accuracy of correlations is better for low gas-liquid ratio wells. 100% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 15% error, while only 53% of the data points lie within ± 15% error. The average absolute percent error, the coefficient of variance and the correlation coefficient are 7.66, 10.1 and zero for gas-liquid ratio less than 350 SCF/STB. While they are 15.2, 20.0 and zero for gas-liquid ratio higher than 350 SCF/STB.

3.4.3 Duns and Ros Correlation [17]

The observed bottom hole pressures and those calculated from Duns and Ros are cross-plotted in Figs. 3.10, 3.11 and 3.12. Figure 3.10 shows the cross-plot with the tubing size as a parameter, Fig. 3.11 shows the cross-plot with the water cut as a parameter, and Fig. 3.12 shows the cross-plot with the gas-liquid ratio as a parameter.

Investigations of these figures shows that the correlation, in general, provides good pressure predictions for most of the tubing

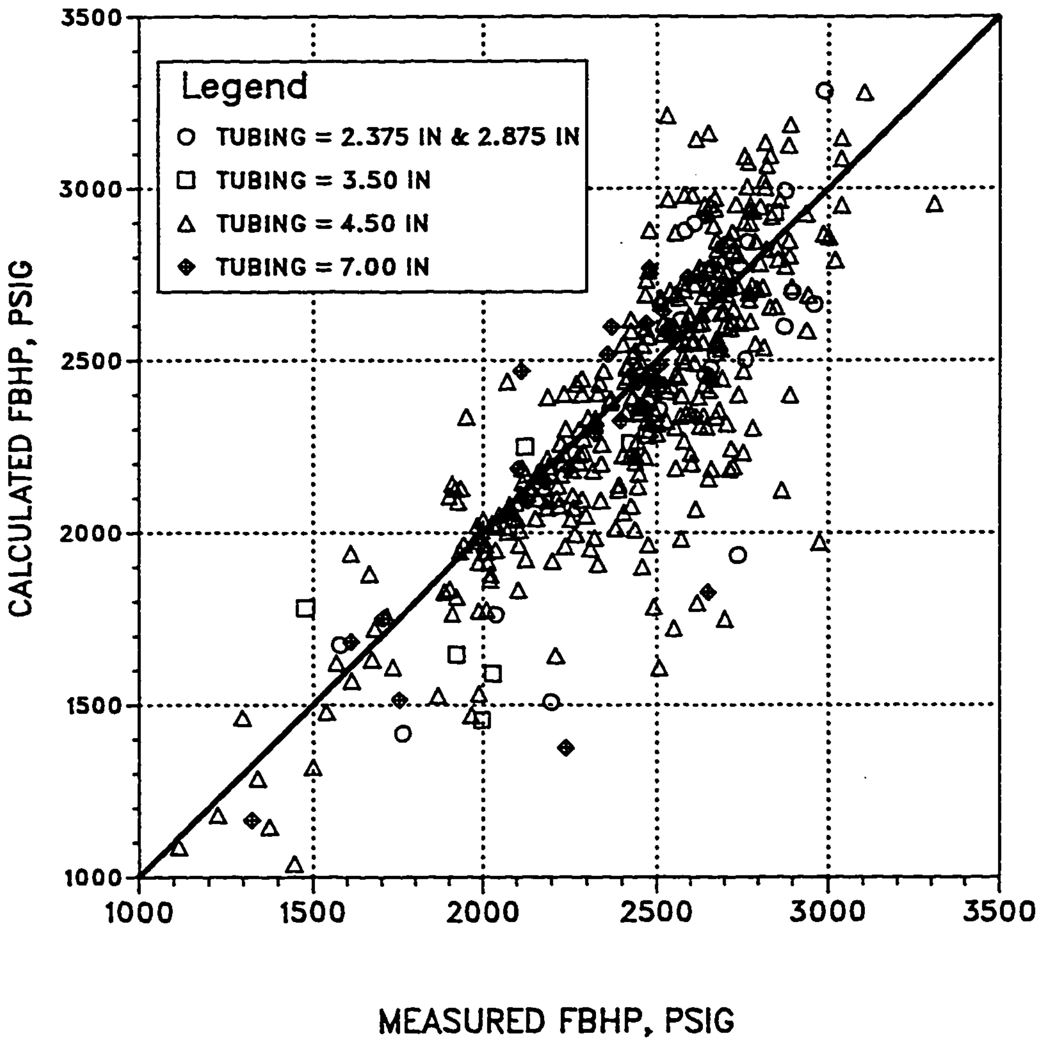


Fig. 3.10: Observed vs. Calculated Pressure using Duns and Ros Correlation with Tubing Size as a Parameter.

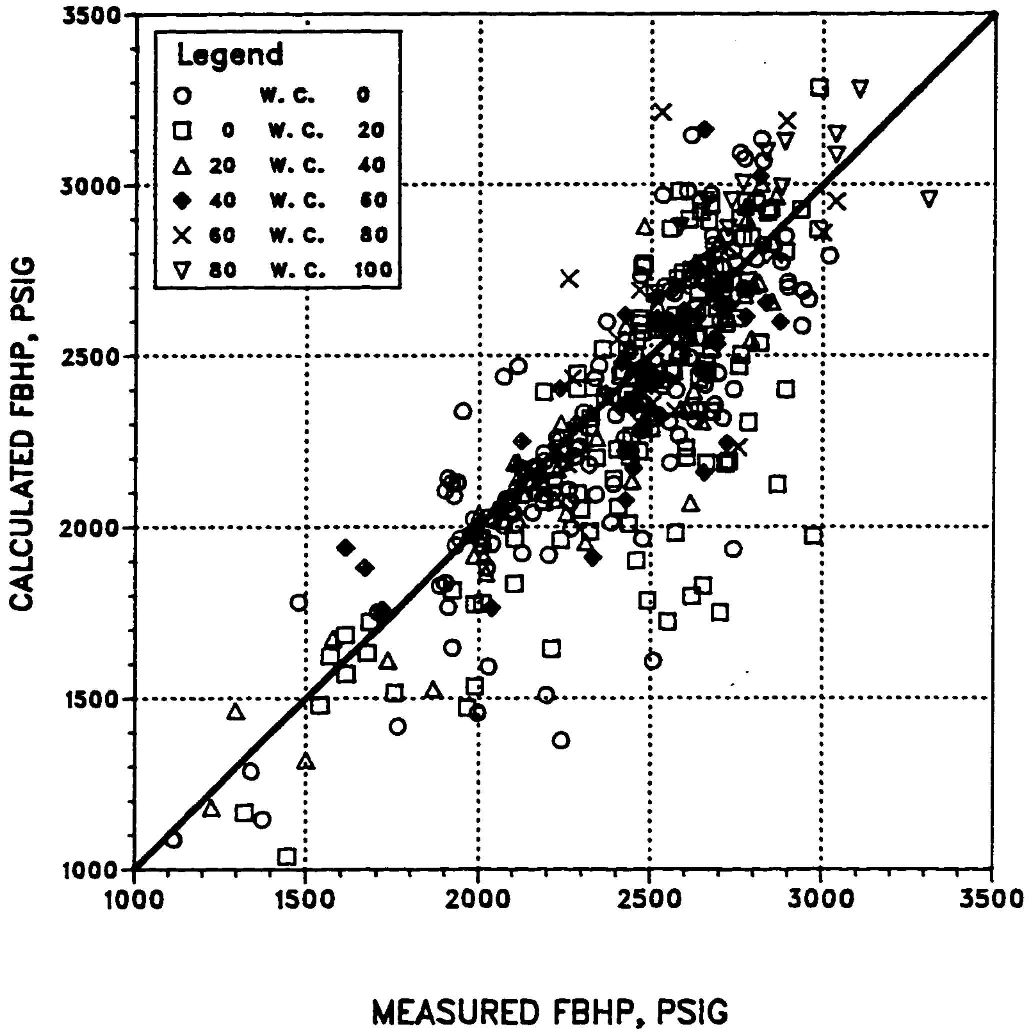


Fig. 3.11: Observed vs. Calculated Pressure using Duns and Ros Correlation with Water Cut as a Parameter.

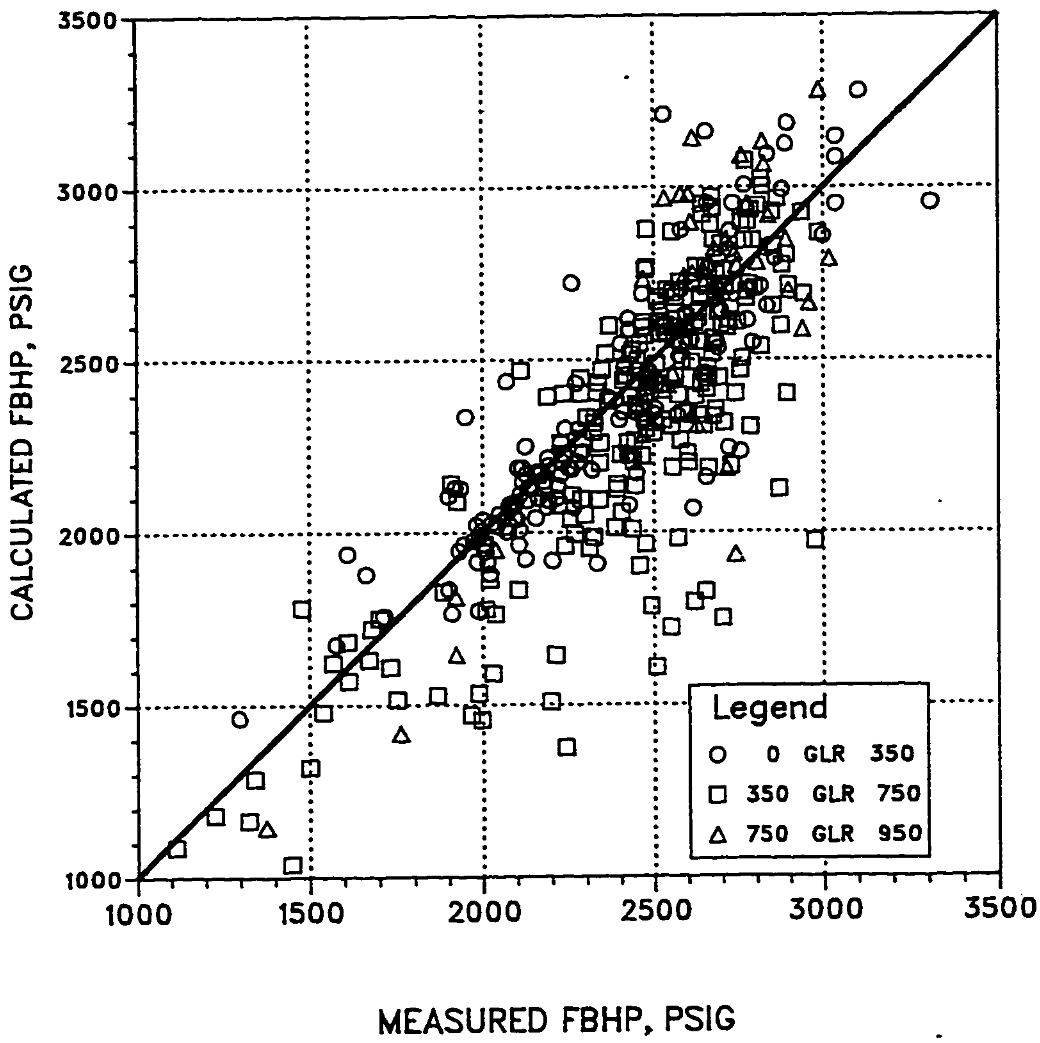
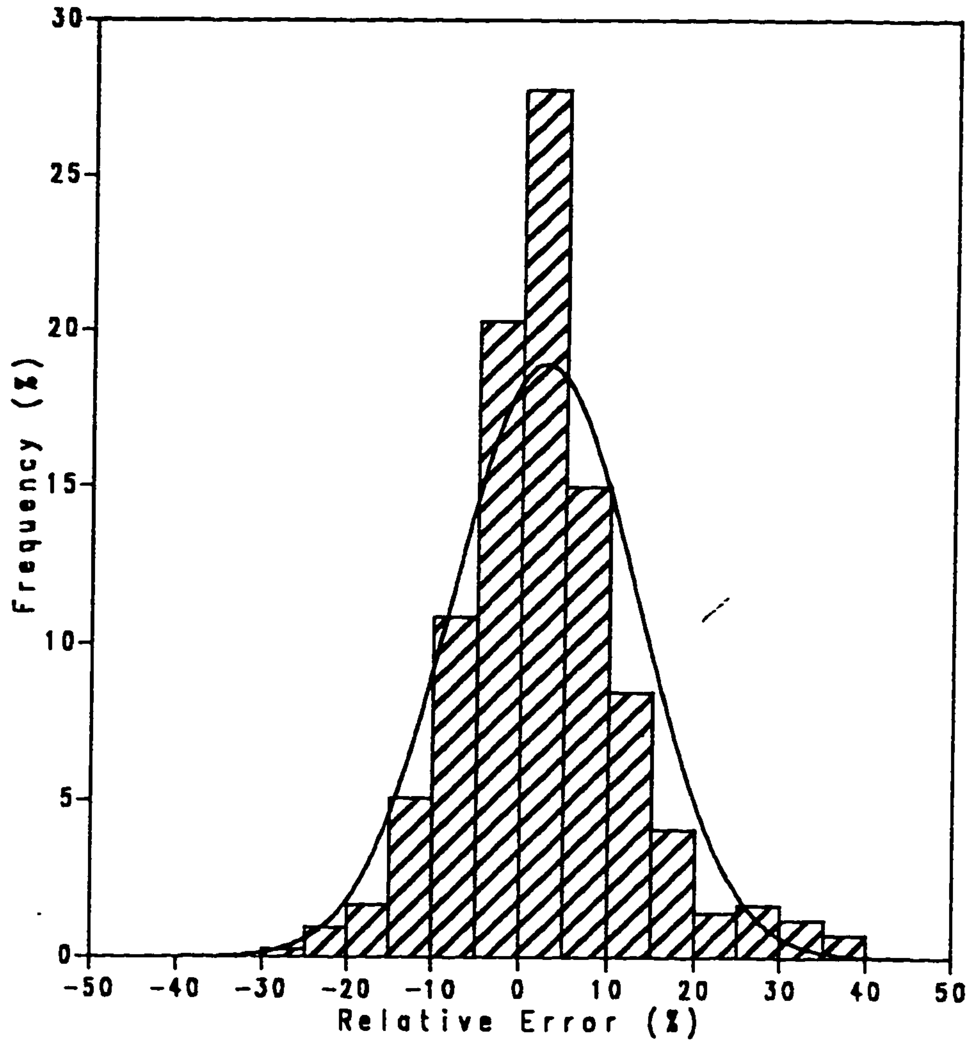


Fig. 3.12: Observed vs. Calculated Pressure using Duns and Ros Correlation with Gas-Liquid Ratio as a Parameter.

sizes with the tendancy to underpredict. For the 23.75 in. and 2.875 in. tubing, the correlation tends to underpredict the pressure drop. It also shows that the correlation tends to underpredict the pressure drop for low percent water cut wells, specially in wells with observed pressure less than 2500 psi. Furthermore, the correlation tends to underpredict the pressure drop for wells with gas-liquid ratio between 350 and 750 SCF/STB and measured pressure less than 2700 psi.

Figure 3.13 shows the error distribution histogram and the normal distribution curve for this correlation. The errors are normally distributed with a mean approximately equals to 3%, indicating a good correlation.

Tables 3.11, 3.12, 3.13 and 3.14 summarize the statistical analysis of the data for different tubing sizes. 70% of the 2.375 in. and 2.875 in. tubings data are predicted within ± 10% error. However, the accuracy of the correlation tends to improve as the gas-liquid ratio decreases. While there is no certain trend as the water cut increases. 80% of the data points of gas-liquid ratio less than 350 SCF/STB are predicted within ± 10% error, while only 58% of the data points of gas-liquid ratio more than 750 SCF/STB are predicted within ± 10% error. The coefficient of variance and the correlation coefficient are 8.32 and 0.91 respectively for gas-liquid ratio less than 350 SCF/STB, and 15.8 and 0.09 respectively for gas-liquid ratio more than 750 SCF/STB.



3.13 Error Distribution for Duns and Ros Correlation.

Table 3.11: Statistical Analysis Results for Duns and Ros Correlation, 2.375 in. and 2.875 in. Tubings

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+5%	+10%	+15%	+20%	+25%	+>25%
Watercut = 0%	14.0	478	18.7	0	7	29%	58%		71%		100%
0 < Watercut < 20%	.5.96	208	7.65	0	8	37%	87%	100%			
20 < Watercut < 100%	13.7	334	14.5	0.83	8	12%	62%	87%			100%
0 < GLR < 350	6.85	203	8.32	0.91	5	20%	80%	100%			
350 < GLR < 750	12.2	350	14.2	0.65	11	36%	72%	81%			100%
750 < GLR < 950	12.5	421	15.8	0.09	7	14%	58%	72%	86%		100%
All Data	11.1	334	13.2	0.67	23	26%	70%	83%	87%		100%

Table 3.12: Statistical Analysis Results for Duns and Ros Correlation, 3.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
All Data	11.4	289	13.1	0.69	10	30%	60%	70%		90%	100%

Table 3.13: Statistical Analysis Results for Dun and Ros Correlation, 4.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	6.81	252	10.7	0.69	117	52%	74%	92%	96%	98%	100%
0 < Watercut < 20%	8.34	298	12.1	0.26	114	48%	68%	82%	89%	92%	100%
20 < Watercut < 40%	5.95	179	7.42	0.88	56	54%	86%	93%	98%	100%	
40 < Watercut < 60%	6.66	216	8.81	0.69	37	49%	79%	87%	98%	100%	
60 < Watercut < 80%	7.84	280	10.8	0	17	53%	76%	82%	88%	94%	100%
80 < Watercut < 100%	6.91	228	7.89	0	11	27%	82%	100%			
0 < GLR < 350	5.67	191	8.17	0.83	126	59%	83%	92%	97%	99%	100%
350 < GLR < 750	8.15	289	11.7	0.48	194	45%	72%	87%	92%	94%	100%
750 < GLR < 950	7.53	248	9.48	0.62	32	47%	66%	85%	97%	100%	
All Data	7.21	254	10.4	0.67	352	50%	75%	88%	94%	96%	100%

Table 3.14: Statistical Analysis Results for Duns and Ros Correlation, 7 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	8.90	308	14.0	0.66	12	58%	75%		92%		100%
0 < Watercut < 100%	7.97	267	11.6	0.73	17	41%	79%	94%			100%
0 < GLR < 350	3.0	82.7	3.65	0.86	6	100%					
350 < GLR < 950	9.7	312	13.8	0.70	23	38%	61%	80%	90%		100%
All Data	8.3	279	12.4	0.70	29	48%	69%	86%	93%		100%

For the 3.5 in. tubing data, the correlation provides a reasonable prediction. 60% of the data points are predicted within ± 10%. The coefficient of variance and the correlation coefficient are 13.1 and 0.69 respectively.

For the 4.5 in. tubing, the correlation is not affected by the water cut. However, the coefficient of variance and the correlation coefficient are 10.7 and 0.69 for the zero water cut data points, while they are 7.89 and zero for water cut greater than 80%. The accuracy of the correlation improves as the gas-liquid ratio decreases. 83% of the data points with gas-liquid ratio less than 350 SCF/STB are predicted within ± 10% error, while 66% of the data points with gas-liquid ratio more than 750 SCF/STB are predicted within ± 10% error. The coefficient of variance and the correlation coefficient for gas-liquid ratio less than 350 SCF/STB are 8.17 and 0.83 while they are 9.48 and 0.62 respectively for gas-liquid ratio more than 750 SCF/STB.

For 7 in. tubing, 69% of the data are predicted within ± 10% error, with coefficient of variance and correlation coefficient of 12.4 and 0.70, indicating good prediction. The accuracy of the correlation tends to improve as the water cut increases. 75% of the data points with zero percent water cut are predicted within ± 10% error, with coefficient of variance and correlation coefficient of 14.0 and 0.66 respectively. While 79% of the data points with water cut greater than zero are predicted within ± 10% error, with coefficient of variance and correlation coefficinet of 11.6 and 0.73 respectively. The accuracy of the correlations tends to improve as the gas-liquid ratio decreases. 100% of the data points with gas-liquid ratio less than 350 SCF/STB are predicted within ± 5% error, with coefficient of variance and correlation coefficient of 3.65 and 0.86 respectively. While only 38% of the data points with gas-liquid ratio greater than 350 SCF/STB are predicted within ± 5% error with coefficient of variance and correlation coefficient of 13.8 and 0.70.

3.4.4 Kabir and Hasan Correlation [30]

The results of testing the Kabir and Hasan correlation against the present bottom hole pressure data are shown in the cross-plots of Figs. 3.14, 3.15 and 3.16. Figure 3.14 shows the cross-plot with the tubing size as a parameter, Fig. 3.15 shows the cross-plot with the water cut as a parameter, and Fig. 3.16 shows the cross-plot with the gas-liquid ratio as a parameter.

Investigation of these figures shows that the correlation tends to underpredict the pressure drop for small tubings, low water cuts and high gas-liquid ratios.

Figure 3.17 shows the error distribution histogram and the normal distribution curve for this correlation. The errors are normally distributed with a mean approximately equals to 4%, indicating a good

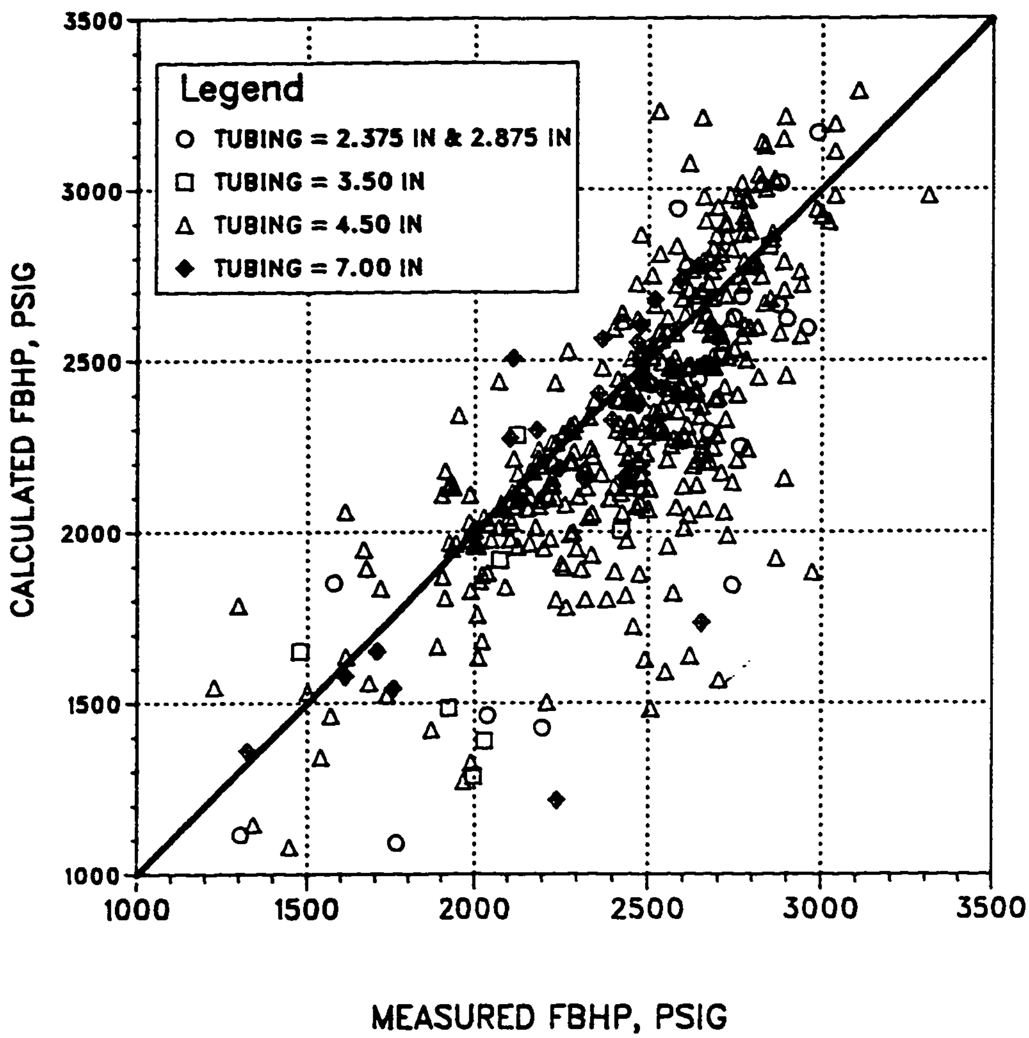


Fig. 3.14: Observed vs. Calculated Pressure using Kabir and Hasan Correlation with Tubing Size as a Parameter.

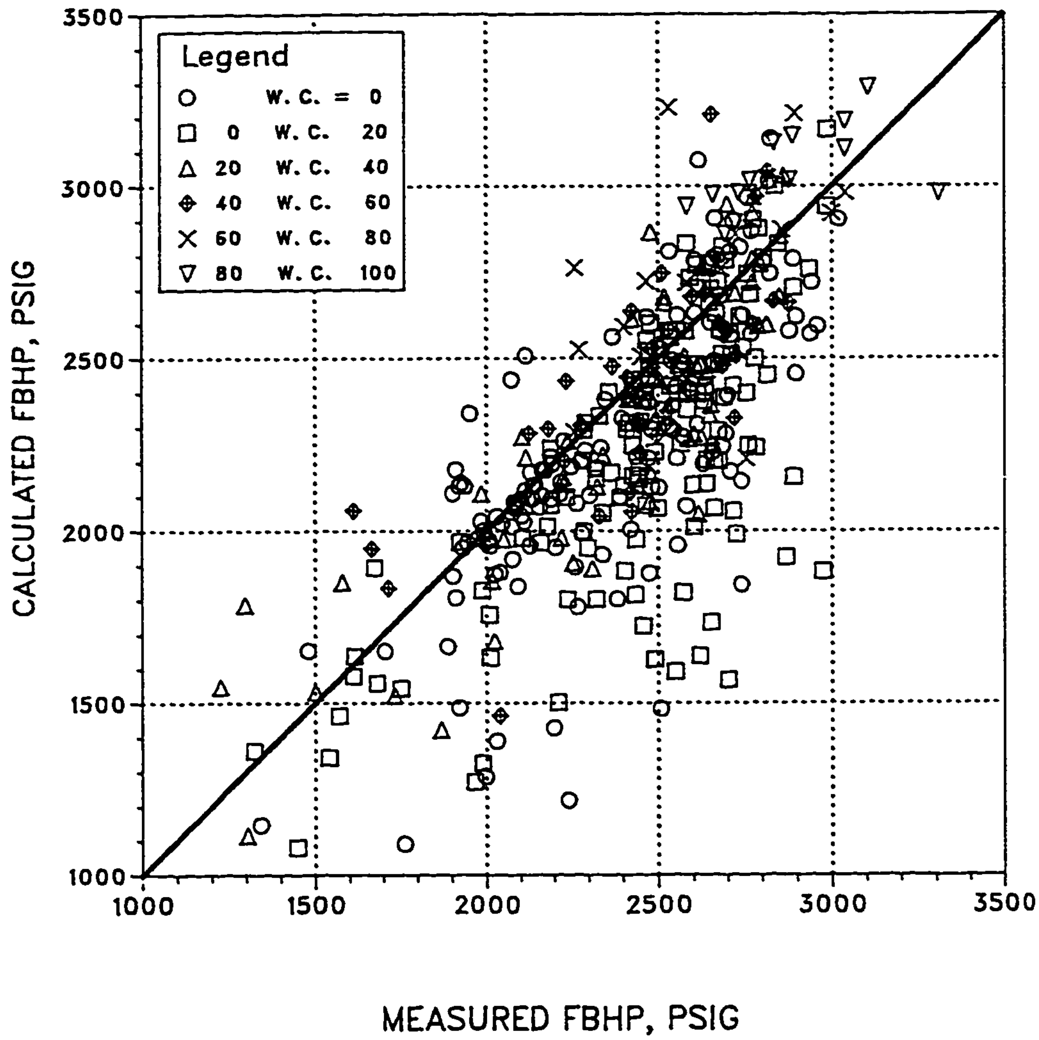


Fig. 3.15: Observed vs. Calculated Pressure using Kabir and Hasan Correlation with Water Cut as a Parameter.

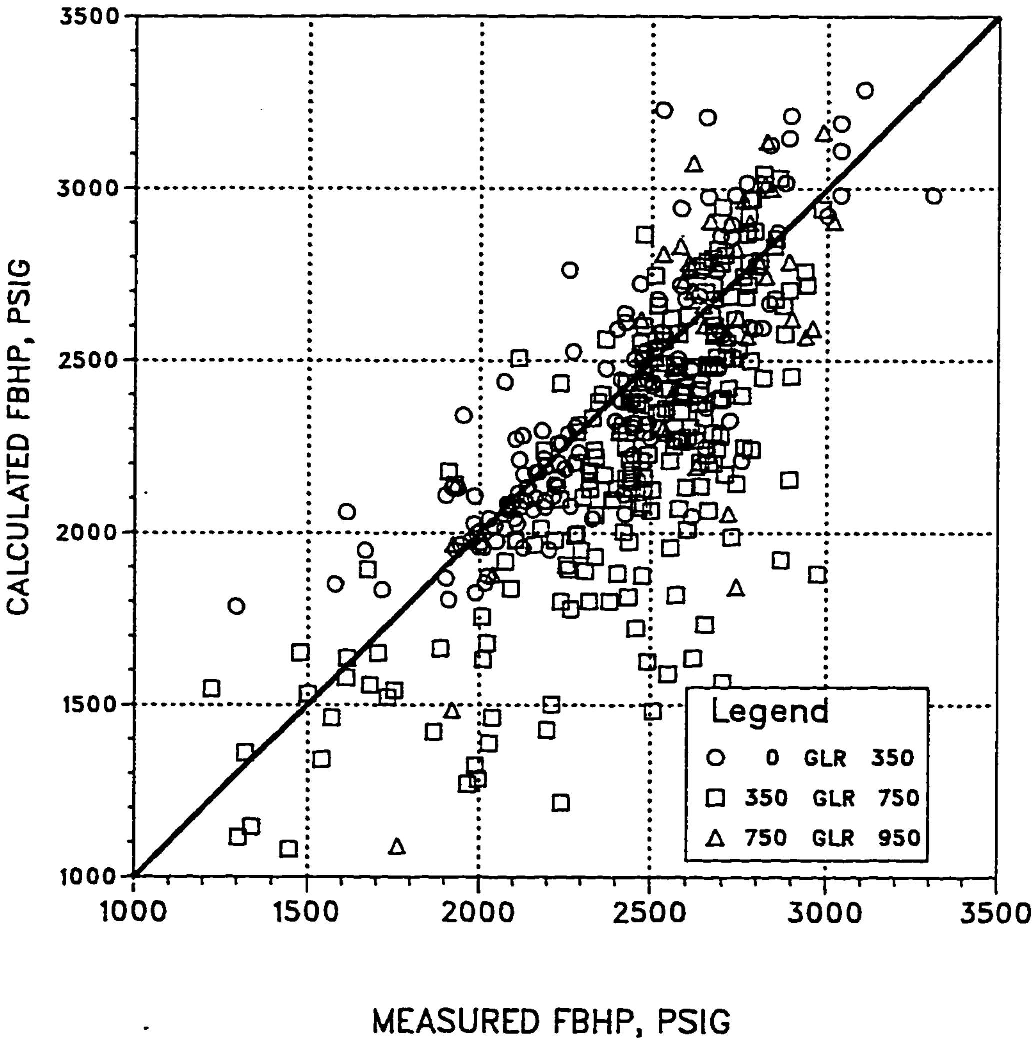
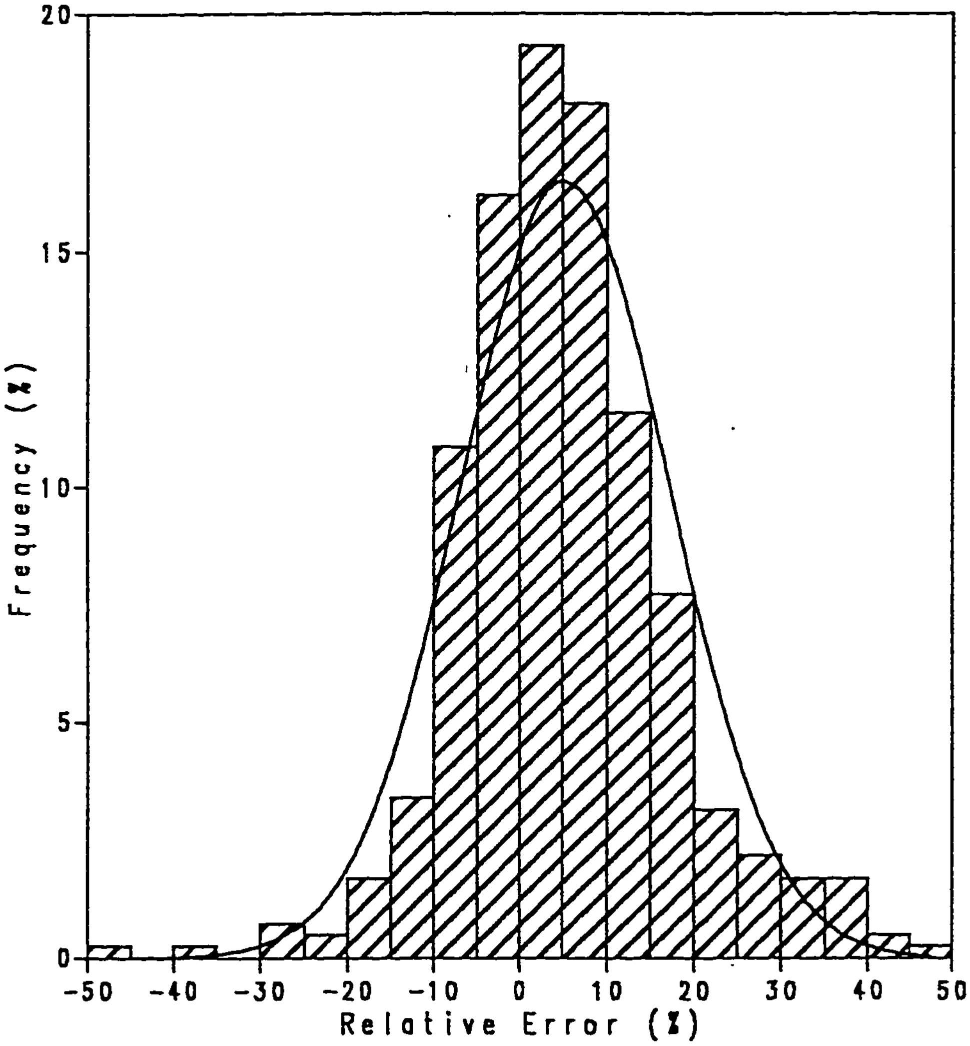


Fig. 3.16: Observed vs. Calculated Pressure using Kabir and Hasan Correlation with Gas-Liquid Ratio as a Parameter.



3.17 Error Distribution for Kabir and Hasan Correlation.

correlation.

Tables 3.15, 3.16, 3.17 and 3.18 summarize the statistical analysis of the data for different tubing sizes. 57% of the 2.375 in. and 2.875 in. tubing data are predicted within ± 10% error. There is no certain trend for the correlation accuracy as the water cut increases. However, the correlation accuracy improves as the gas-liquid ratio decreases. 80% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 15% error, with coefficient of variance and correlation coefficient of 10.6 and 0.86 respectively. While 71% of the data points with gas-liquid ratio more than 750 SCF/STB lie within ± 15% error, with coefficient of variance and correlation coefficient of 18.9 and zero respectively.

For the 3.5 in. tubing, only 40% of the data points lie within ± 10% error, with coefficient of variance and correlation coefficient of 18.3 and zero respectively, indicating the poor prediction of the correlation to predict the pressure drop in 3.5 in. tubing.

For the 4.5 in. tubing data, 65% of the data points lie within ± 10% error, with a coefficient of variance and correlation coefficient of 12.6 and 0.44 respectively. The accuracy of the correlation is not affected by the water cuts while it is affected by the gas-liquid ratio. 52% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 5% error, with coefficient of variance and correlation coefficient of 8.67 and 0.81 respectively. While only 34% of the data points with gas-

Table 3.15: Statistical Analysis Results for Kabir and Hasan Correlation, 2.375 in. and 2.875 in. Tubings

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	19.9	592	23.2	0	7	14%	43%	57%			100%
0 < Watercut < 20%	8.22	281	10.3	0	8	25%	75%	88%	100%		
20 < Watercut < 100%	12.1	312	13.6	0.85	8	25%	50%	75%	87%		100%
0 < GLR < 350	9.3	259	10.6	0.86	5	40%	60%	80%	100%		
350 < GLR < 750	13.2	392	15.9	0.52	11	18%	55%	73%	82%		100%
750 < GLR < 950	15.5	506	18.9	0	7	14%	57%	71%			100%
All Data	13.1	390	15.4	0.49	23	22%	57%	74%	83%		100%

Table 3.16: Statistical Analysis Results for Kabir and Hasan Correlation, 3.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
All Data	14.8	403	18.3	0	10	20%	40%	60%	70%	80%	100%

Table 3.17: Statistical Analysis Results for Kabir and Hasan Correlation, 4.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	8.42	284	12.0	0.58	117	44%	65%	81%	93%	97%	100%
0 < Watercut < 20%	10.5	386	15.6	0	114	29%	56%	72%	83%	87%	100%
20 < Watercut < 40%	8.25	234	9.71	0.78	56	35%	67%	83%	92%	96%	100%
40 < Watercut < 60%	7.74	229	9.33	0.64	37	35%	78%	86%	94%	97%	100%
60 < Watercut < 80%	8.09	293	11.3	0	17	48%	65%	82%	88%	94%	100%
80 < Watercut < 100%	7.76	246	8.53	0	11	9%	82%	100%			
0 < GLR < 350	6.25	203	8.67	0.81	126	52%	81%	91%	96%	98%	100%
350 < GLR < 750	11.5	367	14.9	0	194	25%	51%	72%	86%	91%	100%
750 < GLR < 950	7.99	249	9.53	0.61	32	34%	78%	88%	94%	97%	100%
All Data	9.30	307	12.6	0.44	352	36%	65%	80%	90%	94%	100%

Table 3.18: Statistical Analysis Results for Kabir and Hasan Correlation, 7 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	10.2	355	16.1	0.49	12	58%	75%		83%		100%
0 < Watercut < 100%	7.33	272	11.8	0.72	17	47%	82%	94%			100%
0 < GLR < 350	4.53	124	5.48	0.64	6	50%	100%				
350 < GLR < 950	9.55	337	14.9	0.63	23	52%	74%	83%	88%		100%
All Data	8.5	303	13.4	0.64	29	52%	80%	87%	90%		100%

liquid ratio more than 750 SCF/STB lie within ± 5% error, with coefficient of variance and correlation coefficient of 9.53 and 0.61 respectively.

For the 7 in. tubing data, 80% of the data points lie within ± 10% error, with coefficient of variance and correlation coefficient of 13.4 and 0.64 respectively. The accuracy of the correlation in predicting the pressure drop improves as the water cut increases. 75% of the data points with zero percent water cut lie within ± 10% error with coefficient of variance and correlation coefficient of 16.1 and 0.49 respectively. While 82% of the data points with water cut more than zero are predicted within ± 10% error, with coefficient of variance and correlation coefficient of 11.8 and 0.72 respectively. The accuracy of the correlation improves as the gas-liquid ratio decreases. 100% of the data points with gas-liquid ratio less than 350 SCF/STB lie within ± 10% with coefficient of variance and correlation coefficient of 5.48 and 0.64 respectively. While 74% of the data points with gas-liquid ratio more than 350 SCF/STB lie within ± 10%, with coefficient of variance and correlation coefficient of 14.9 and 0.63 respectively.

3.4.5 Orkiszewski Correlation [39]

The bottom hole pressures calculated from Orkiszewski correlation are compared against the measured values in Figs. 3.18, 3.19 and 3.20. Figure 3.18 shows the cross-plot with the tubing size as a parameter,

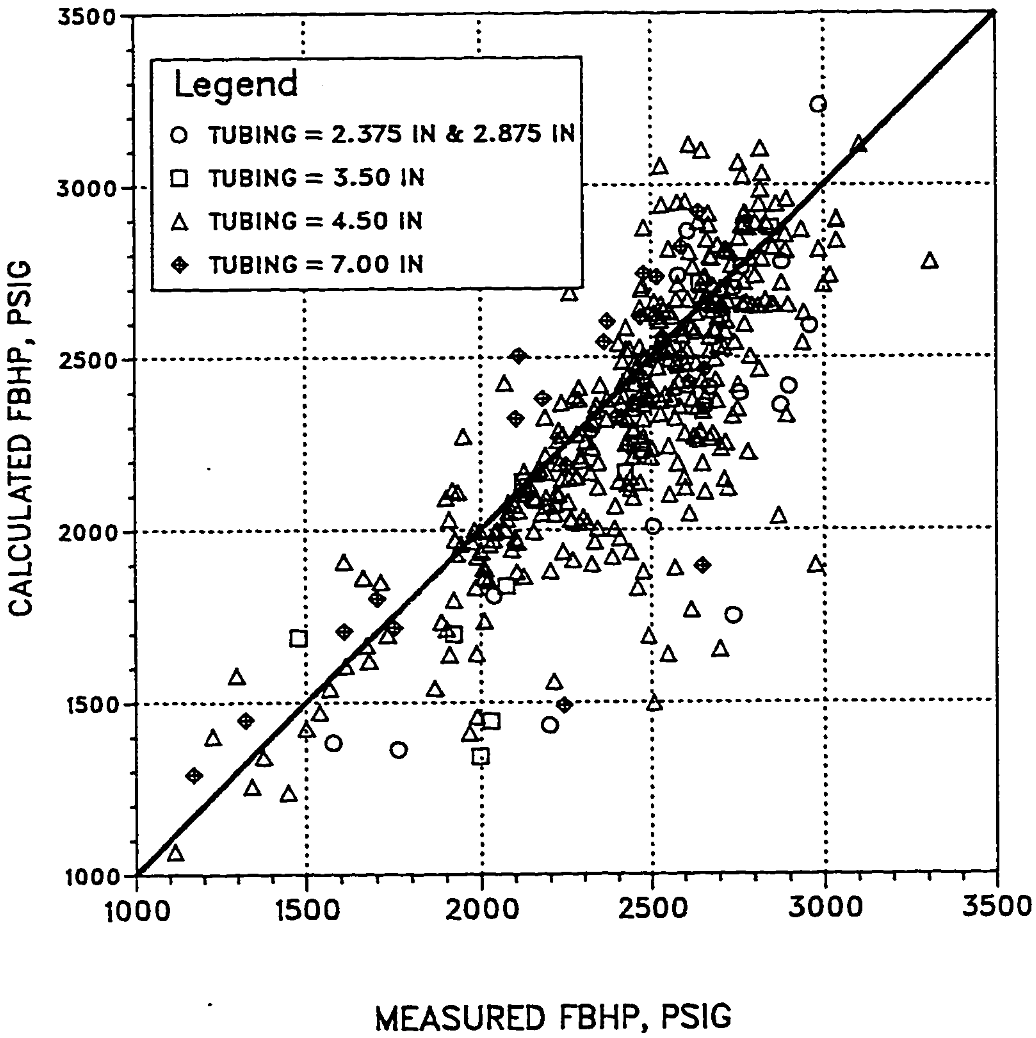


Fig. 3.18: Observed vs. Calculated Pressure using Orkiszewski Correlation with Tubing Size as a Parameter.

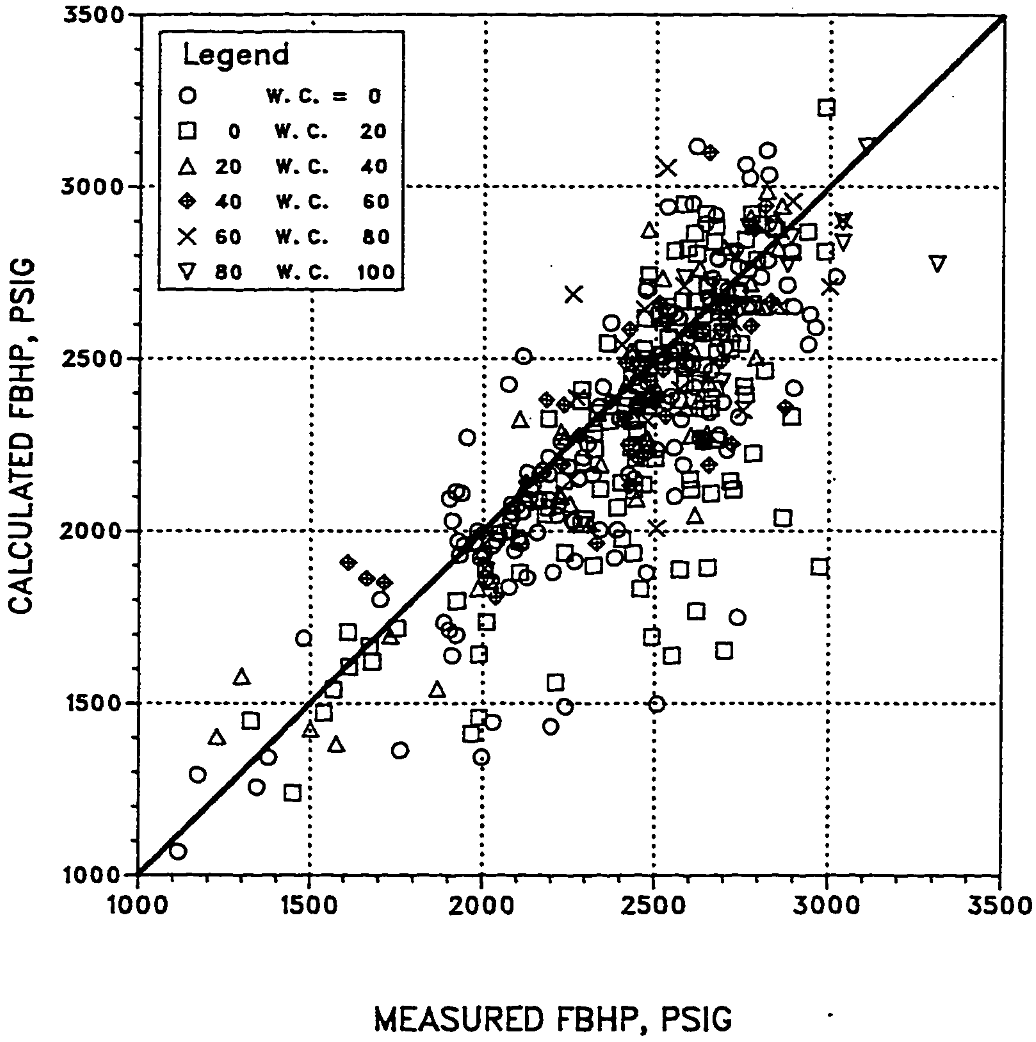


Fig. 3.19: Observed vs. Calculated Pressure using Orkiszewski Correlation with Water Cut as a Parameter.

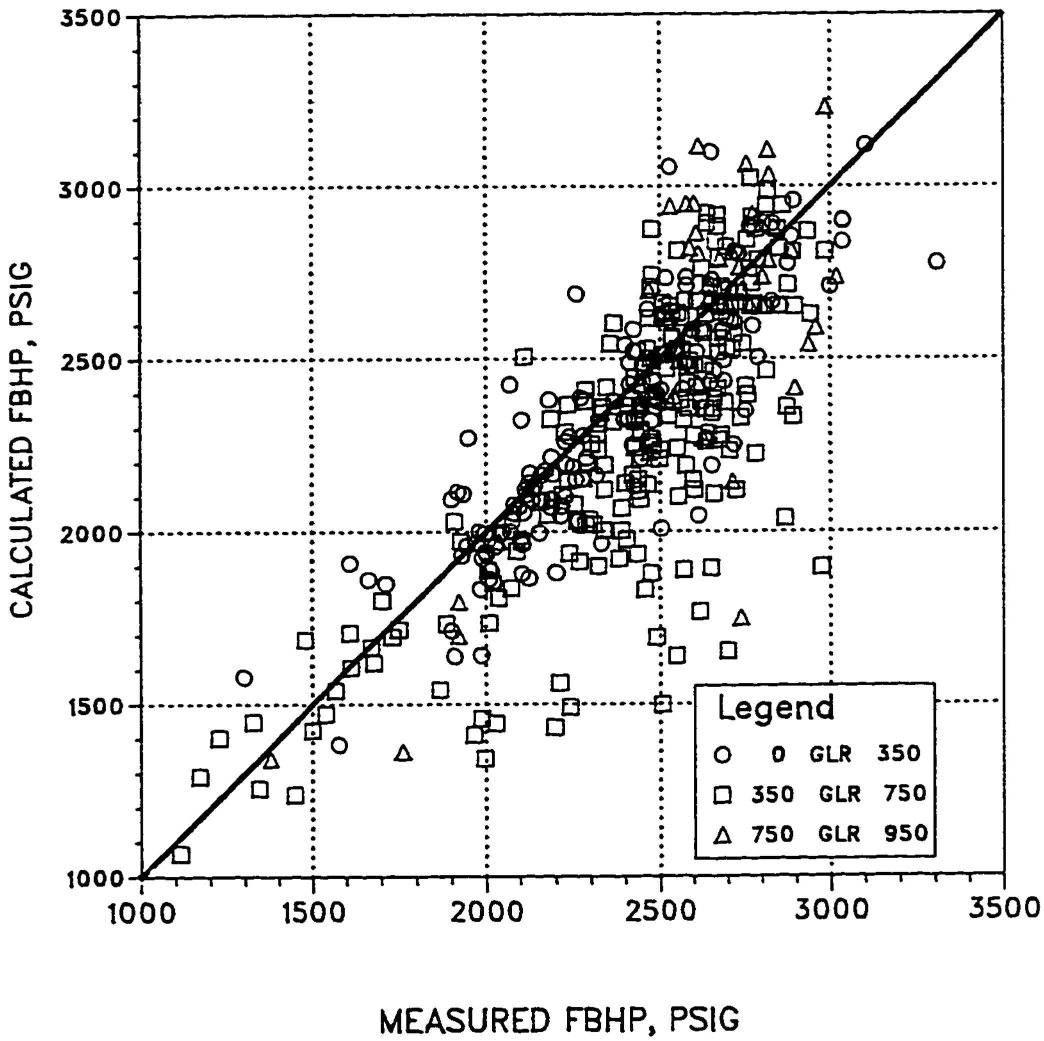


Fig. 3.20: Observed vs. Calculated Pressure using Orkiszewski Correlation with Gas-Liquid Ratio as a Parameter.

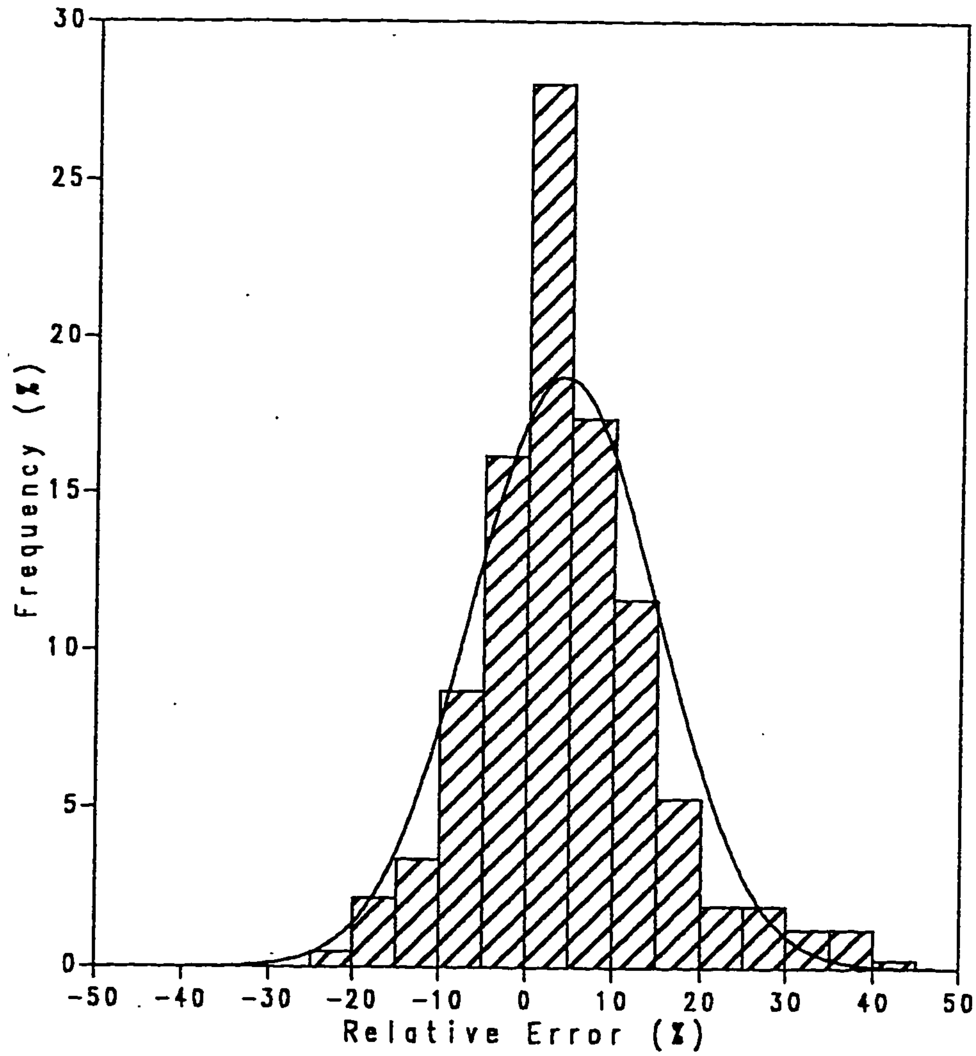
Fig. 3.19 shows the cross-plot with the water cut as a parameter, and Fig. 3.20 shows the cross-plot with the gas-liquid ratio as a parameter.

Investigation of these figures shows that the correlation tends to underpredict the bottom hole pressure for small tubings and overpredict the bottom hole pressure for large tubings. Furthermore, the correlation provides, in general, good prediction for high water cut wells.

Figure 3.21 shows the error distribution histogram and the normal distribution curve for this correlation. The errors are normally distributed with a mean approximately equals to 3%, indicating a good correlation.

Tables 3.19, 3.20, 3.21 and 3.22 summarize the statistical analysis of the data for different tubing sizes. For the 2.375 in. and 2.875 in. tubing, only 44% of the data points are predicted within ± 10% error. The correlation is not affected by the water cuts percent. However, it is affected by the gas-liquid ratio. 80% of the tubing data points of gas-liquid ratio less than 350 SCF/STB are predicted within ± 15%, with a coefficient of variance and correlation coefficient of 13.9 and 0.74 respectively. While only 58% of the data points with gas-liquid ratio more than 750 SCF/STB are predicted within ± 15% with a coefficient of variance and correlation coefficient of 19.5 and zero respectively.

For the 3.5 in. tubing, only 30% of the tubing data are predicted



3.21 Error Distribution for Orkiszewski Correlation.

Table 3.19: Statistical Analysis Results for Orkiszewski Correlation, 2.375 in. and 2.875 in. Tubings

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	18.3	593	23.2	0	7	29%	29%	43%	57%	71%	100%
0 < Watercut < 20%	7.20	247	9.10	0	8	37%	74%	100%			
20% < Watercut < 100%	15.4	382	16.6	0	8	12%	25%	62%	87%		100%
0 < GLR < 350	11.2	338	13.9	0.74	5	20%	40%	80%	100%		
350 < GLR < 750	13.2	383	15.5	0.55	11	36%	45%	72%	81%		100%
750 < GLR < 950	15.3	522	19.5	0	7	14%	44%	58%	72%	86%	100%
All Data	13.4	402	15.9	0.44	23	26%	44%	70%	83%	87%	100%

Table 3.20: Statistical Analysis Results for Orkiszewski Correlation, 3.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
All Data	12.4	342	15.5	0.51	10	3%	30%	40%	80%		100%

Table 3.21: Statistical Analysis Results for Orkiszewski Correlation, 4.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	7.60	270	11.5	0.63	117	45%	71%	88%	97%	98%	100%
0 < Watercut < 20%	9.38	333	13.5	0	114	44%	64%	80%	86%	90%	100%
20% < Watercut < 40%	6.43	189	7.86	0.87	56	48%	82%	92%	96%	100%	
40% < Watercut < 60%	6.16	196	8.02	0.75	37	54%	81%	86%	100%		
60% < Watercut < 80%	7.35	241	9.26	0.25	17	35%	82%	88%	94%	100%	
80% < Watercut < 100%	4.84	211	7.29	0	11	73%	91%		100%		
0 < GLR < 350	6.03	189	8.04	0.84	126	54%	81%	90%	98%	100%	
350 < GLR < 750	8.97	317	12.8	0.26	194	42%	68%	83%	91%	94%	100%
750 < GLR < 950	7.06	243	9.28	0.64	32	47%	72%	91%	97%	100%	
All Data	7.74	270	11.1	0.61	352	46%	72%	85%	93%	96%	100%

Table 3.22: Statistical Analysis Results for Orkiszewski Correlation, 7 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	8.32	280	12.7	0.73	12	50%	75%	84%	93%		100%
0 < Watercut < 100%	8.06	258	11.2	0.75	17	24%	76%	94%			100%
0 < GLR < 350	5.90	170	7.49	0	6	50%	83%	100%			
350 < GLR < 950	8.70	284	12.6	0.76	21	33%	71%	85%	90%		100%
All Data	8.10	262	11.6	0.74	29	35%	76%	90%	93%		100%

with ± 10% error. The average absolute percent error, the coefficient of variance, and the correlation coefficient are 12.4, 15.5 and 0.51 respectively, indicating the poor prediction of the bottom hole pressure by the correlation.

For the 4.5 in. tubing data, 72% of the data points are predicted within ± 10% error, with an average absolute percent error, coefficient of variance and correlation coefficient of 7.74, 11.1 and 0.61 respectively, indicating that the correlation predicts the bottom hole pressure within an acceptable range. The accuracy of the correlation improves as the water cut increases and gas-liquid ratio decreases. 71% of the tubing data points with zero water cut lie within ± 10% error with a coefficient of variance and correlation coefficient of 11.5 and 0.63, while 82% of the tubing data points with water cuts between 20% and 40%, lie within ± 10%, with coefficient of variance and correlation coefficient of 7.86 and 0.87 respectively. 81% of the tubing data points with gas-liquid ratio less than 350 SCF/STB are predicted within ± 10% errors, with coefficient of variance and correlation coefficient of 8.04 and 0.84 respectively. While 72% of the tubing data points with gas-liquid ratio more 750 SCF/STB lie within ± 10% error with a coefficient of variance and correlation coefficient of 11.1 and 0.61 respectively.

For the 7 in. tubing data, 76% data are predicted within ± 10%, with a coefficient of variance and correlation coefficient of 11.6 and 0.74 respectively. The accuracy of the correlation is not affected by the water cut percent. However, it is affected by the gas-liquid ratio. 83% of the tubing data with gas-liquid ratio less than 350 SCF/STB are predicted within ± 10% error, with a coefficient of variance and correlation coefficient of 7.49 and zero respectively. While 71% of the data with gas-liquid ratio more than 350 SCF/STB are predicted within ± 10% error, with a coefficient of variance and correlation coefficient of 12.6 and 0.76 respectively.

3.4.6 Beggs and Brill Correlation [4]

Figures 3.22, 3.23 and 3.24 represent cross-plots of the observed and calculated bottom hole pressures using Beggs and Brill correlation. The figures respectively present the data with the tubing size as a parameter, with the water cut as a parameter, and with the gas-liquid ratio as a parameter.

Investigation of these figures shows that the correlation provides, in general, good pressure drop predictions. It shows that the correlation tends to underpredict the pressure drop for the smaller tubing and overpredict it for the larger tubings. The correlation tends to underpredict the pressure drop for the zero water cut, and overpredict the pressure drop in wells with high water cuts. Furthermore, it tends to overpredict the pressure drop in wells with low gas-liquid ratio.

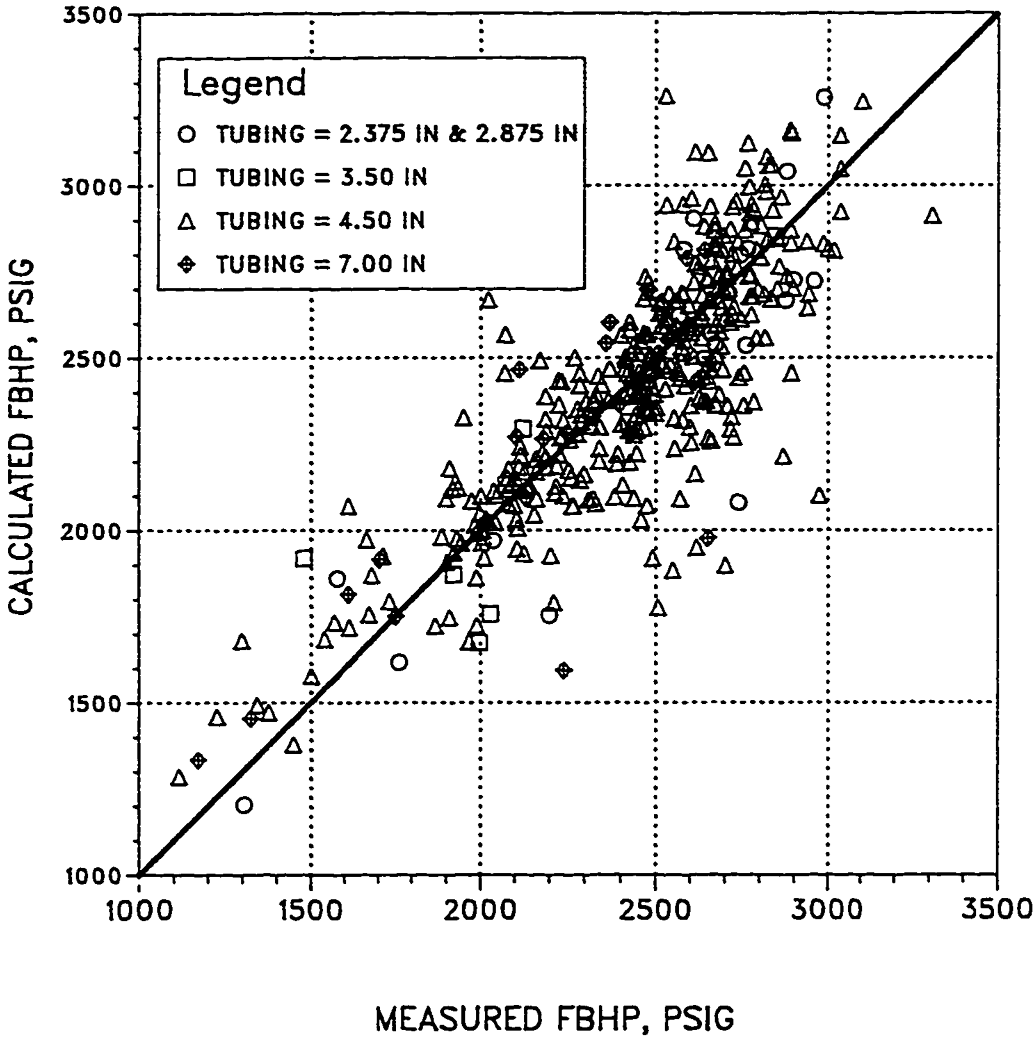


Fig. 3.22: Observed vs. Calculated Pressure using Beggs and Brill Correlation with Tubing Size as a Parameter.

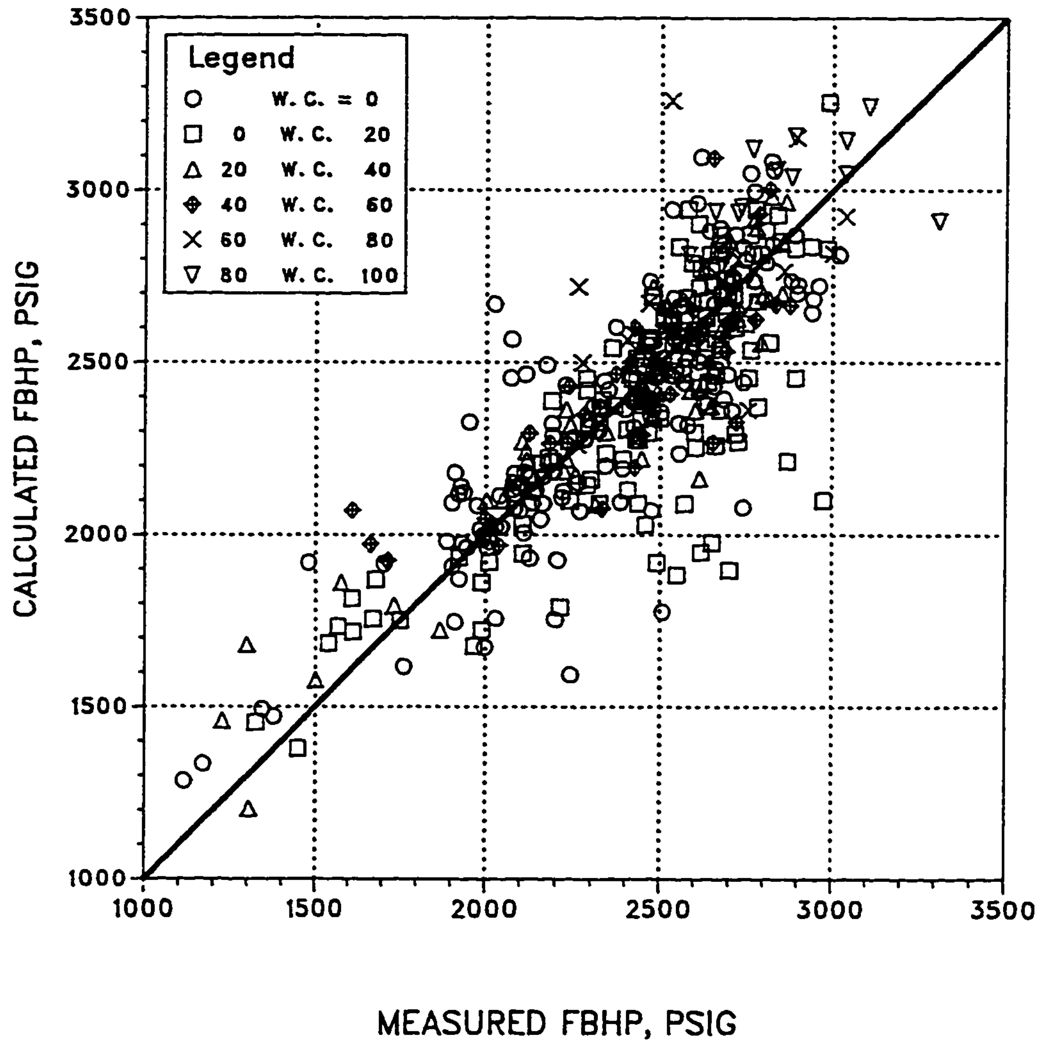


Fig. 3.23: Observed vs. Calculated Pressure using Beggs and Brill Correlation with Water Cut as a Parameter.

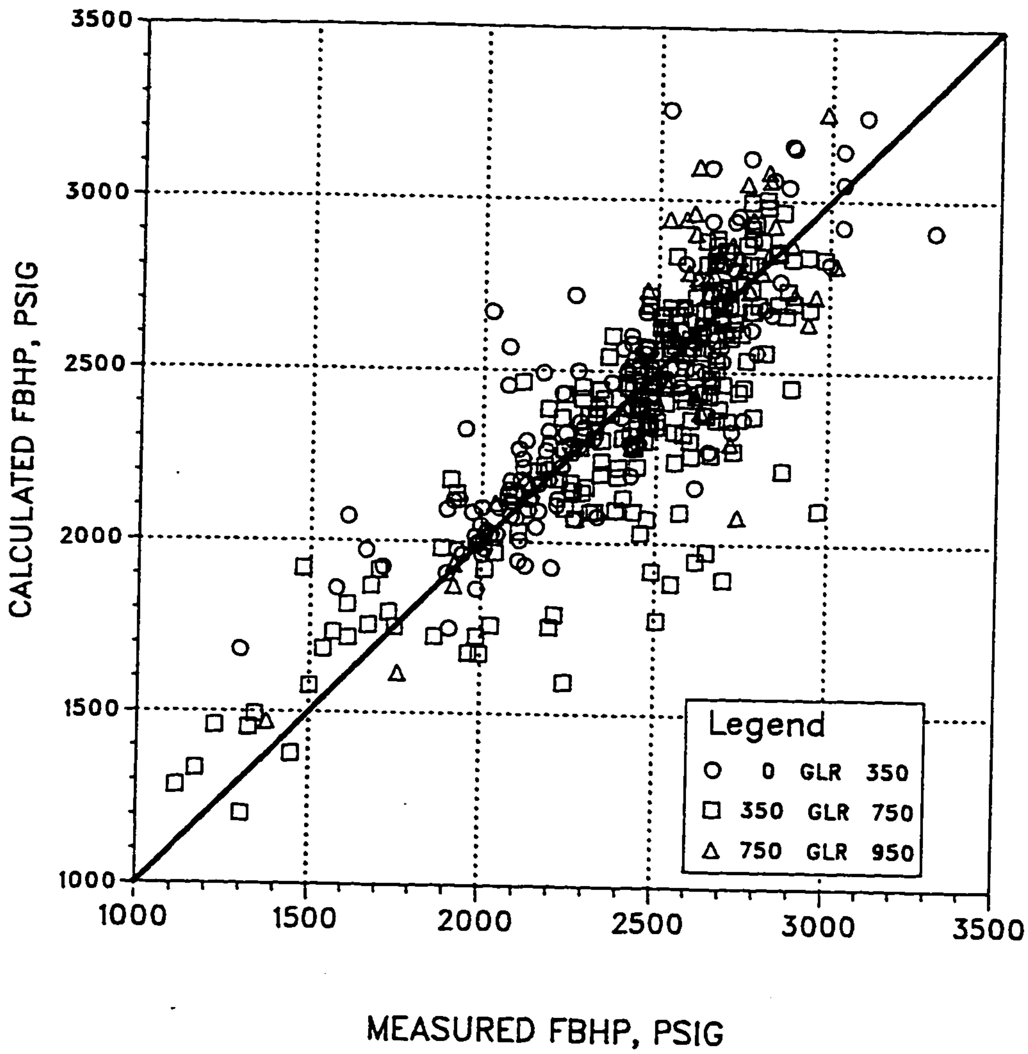


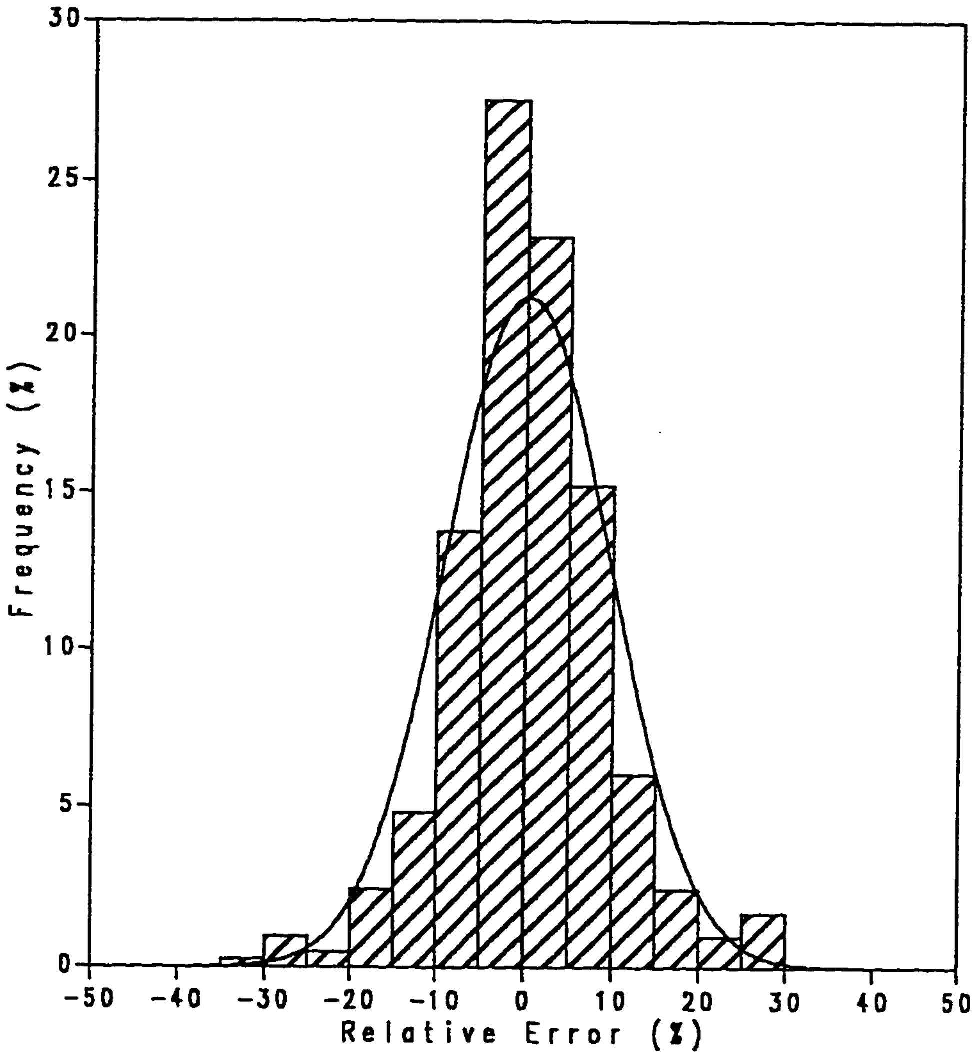
Fig. 3.24: Observed vs. Calculated Pressure using Beggs and Brill Correlation with Gas-Liquid Ratio as a Parameter.

Figure 3.25 shows the error distribution histogram and the normal distribution curve for this correlation. It shows that the mean is almost at the zero line, indicating good correlation.

Tables 3.23, 3.24, 3.25 and 3.26 summarize the statistical analysis of the data for different tubing sizes. For the 2.375 in. and 2.875 in. tubing data, 83% of the tubing data points are predicted within ± 10%, with a coefficient of variance and correlation coefficient of 9.34 and 0.85 respectively. The accuracy of the correlation improves as the water cut increases. The coefficient of variance and the correlation coefficient for the zero water cut are 13.8 and 0.57 respectively, while they are 8.04 and 0.95 respectively for water cut percent higher than 20%. Also, the accuracy of the correlation improves as the gas-liquid ratio decreases. The coefficient of variance and the correlation coefficient for the gas-liquid ratio more than 750 SCF/STB are 9.34 and 0.85, whereas they are 8.73 and 0.90 for gas-liquid ratio less than 350 SCF/STB.

For the 3.5 in. tubing, 70% of the tubing data points lie within ± 10% error, with a coefficient of variance and correlation coefficient of 10.2 and 0.83 respectively, indicating the correlation is a good correlation to predict the pressure drop in the 3.5 in. tubing.

For the 4.5 in. tubing, 80% of the tubing data points lie within ± 10% error. The average absolute percent error, the coefficient of variance and the correlation coefficient are 6.58, 9.18 and 0.76



3.25 Error Distribution for Beggs and Brill Correlation.

Table 2.23: Statistical Analysis Results for Beggs and Brill Correlation, 2.375 in. and 2.875 in. Tubings

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	9.88	352	13.8	0.57	7	29%	71%			100%	
0 < Watercut < 20%	5.18	185	6.82	0	8	50%	87%	100%			
20% < Watercut < 100%	7.16	185	8.04	0.95	8	25%	87%		100%		
0 < GLR < 350	7.78	212	8.73	0.90	5	20%	80%		100%		
350 < GLR < 750	5.50	184	7.46	0.92	11	55%	91%			100%	
750 < GLR < 950	9.78	342	12.8	0.59	7	14%	72%	86%		100%	
All Data	7.30	236	9.34	0.85	23	35%	83%	87%	91%	100%	

Table 3.24: Statistical Analysis Results for Beggs and Brill Correlation, 3.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
All Data	8.73	224	10.2	0.83	10	50%	70%	80%	90%		100%

Table 3.25: Statistical Analysis Results for Beggs and Brill Correlation, 4.5 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	6.87	236	10.1	0.74	117	50%	77%	92%	97%	98%	100%
0 < Watercut < 20%	6.79	243	9.86	0.61	114	54%	77%	88%	94%	96%	100%
20% < Watercut < 40%	5.22	151	6.25	0.92	56	57%	92%	94%	98%		100%
40% < Watercut < 60%	6.37	192	7.82	0.77	37	51%	81%	92%	97%		100%
60% < Watercut < 80%	7.55	272	10.4	0	17	53%	82%	88%		94%	100%
80% < Watercut < 100%	7.43	251	8.68	0	11	36%	72%	100%			
0 < GLR < 350	6.27	201	8.59	0.81	126	58%	82%	91%	95%	97%	100%
350 < GLR < 750	6.82	239	9.67	0.69	194	50%	80%	91%	96%	97%	100%
750 < GLR < 950	6.36	219	8.36	0.72	32	47%	75%	91%	100%		
All Data	6.58	224	9.18	0.76	352	52%	80%	91%	96%	97%	100%

Table 3.26: Statistical Analysis Results for Beggs and Brill Correlation, 7 in. Tubing

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Watercut = 0%	8.10	254	11.5	0.78	12	50%	67%	84%	92%		100%
0 < Watercut < 100%	6.74	220	9.59	0.82	17	35%	82%	94%			100%
0 < GLR < 350	3.41	98.9	4.37	0.79	6	83%	100%				
350 < GLR < 950	8.32	256	11.3	0.81	23	38%	71%	85%	90%		100%
All Data	7.30	231	10.2	0.81	29	45%	80%	90%	93%		100%

respectively, which indicates the correlation provides good pressure drop prediction. The accuracy of the correlation is not affected by the water cut percent. However, it is affected by the gas-liquid ratio. 82% of the tubing data with gas-liquid ratio less than 350 SCF/STB are predicted within ± 10% error, with a coefficient of variance and correlation coefficient of 8.59 and 0.81 respectively. While 75% of the data with gas-liquid ratio more than 750 SCF/STB are predicted within ± 10%, with a coefficient of variance and correlation coefficient of 8.36 and 0.72.

For the 7 in. tubing, 80% of the tubing data points are predicted within ± 10%, with an average absolute percent error, coefficient of variance and correlation coefficient of 7.30, 10.2 and 0.81 respectively, indicating good correlation to predict the pressure drop in the 7 in. tubing. The accuracy of the correlation improves as the water cut increases. 67% of the tubing data points with zero water cut are predicted within ± 10% error, with a coefficient of variance and correlation coefficient of 11.5 and 0.78 respectively. While 82% of the data with water cut higher than zero predicted within ± 10% error, with a coefficient of variance and correlation coefficient of 9.59 and 0.82 respectively. The accuracy of the correlation tends to improve as the gas-liquid ratio decreases. 100% of the data with gas-liquid ratio less than 350 SCF/STB lie within ± 10% error, with a coefficient of variance and correlation coefficient of 4.37 and 0.79, while only 71% of the data points with gas-liquid ratio more than 350 SCF/STB lie within

± 10% error, with a coefficinet of variance and correlation coefficient of 11.3 and 0.81 respectively.

3.5 Comparison of Correlations

In this section, the six correlations evaluated in the previous section are compared against each other with regard to their accuracy of pressure-drop prediction. For this purpose, the data are first divided into four groups according to the tubing size (i.e. data for 2.375 in and 2.875 in., data for 3.5 in., data for 4.5 in. and data for 7 in. tubings). The data for each tubing size are used separately to study the effects of gas-liquid ratio (GLR), water cut (WC) and rate on the accuracy of the correlations. Then a comparison is made using all data. The effect of tubing size on the accuracy of the correlation is then studied.

The results of the comparison are first presented in graphical form where the average percent error (APE) and average absolute percent error (AAPE) are plotted against the parameter of interest (i.e. GLR, WC or rate) for all six correlations. The detailed statistical parameters are then tabulated.

3.5.1 Effect of Gas-Liquid Ratio

The average absolute percent errors for all six correlations are plotted against the gas-liquid ratio for the 2.375 in. and 2.875 in. data in Fig. 3.26. Similarly, the results are shown in Figs. 3.27, 3.28 and 3.29 for the data of the 3.5 in. 4.5 in. and 7 in. tubings respectively. Figure 3.30 compares the errors calculated for all correlations using the data from all tubings combined.

Investigation of these figures shows that for 2.375 in., 2.875 in., and 3.5 in. tubings, the data with gas-liquid ratio less than 250 SCF/STB are predicted within ± 10% error by almost all the correlations. It also shows that the correlation of Beggs and Brill and Hagedorn and Brown are superior to the rest of the correlations. Further, Aziz and Govier correlation is the least accurate correlation for gas-liquid ratio greater than 350 SCF/STB. For the 4.5 in. tubings,all the correlations show good prediction except those of Aziz and Govier, and Kabir and Hasan for gas-liquid ratios greater than 350 SCF/STB. The two correlations tend to predict the pressure drop in wells with gas-liquid ratio more than 350 SCF/STB with an absolute percent error more than 10%.

For the 7 in. tubing, all the correlations, except Aziz and Govier correlation, tend to predict the pressure drop in wells with gas-liquid ratios less than 350 SCF/STB within an average absolute percent error less than 10% error. For gas-liquid ratio between 350 SCF/STB and 550

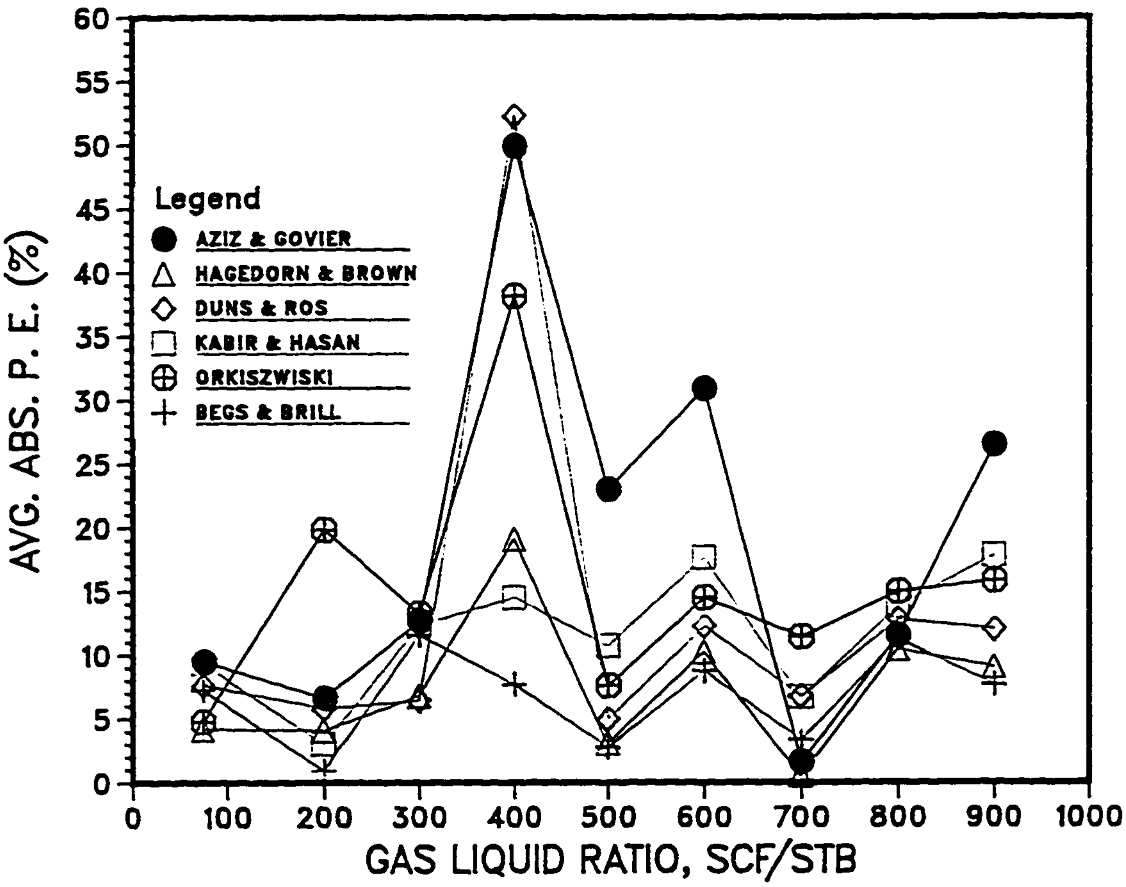


Fig. 3.26: Comparison of the Average Absolute Percent Error for all Correlations using 2.375 in. and 2.875 in Tubing Size with Gas-Liquid Ratio as a Parameter.

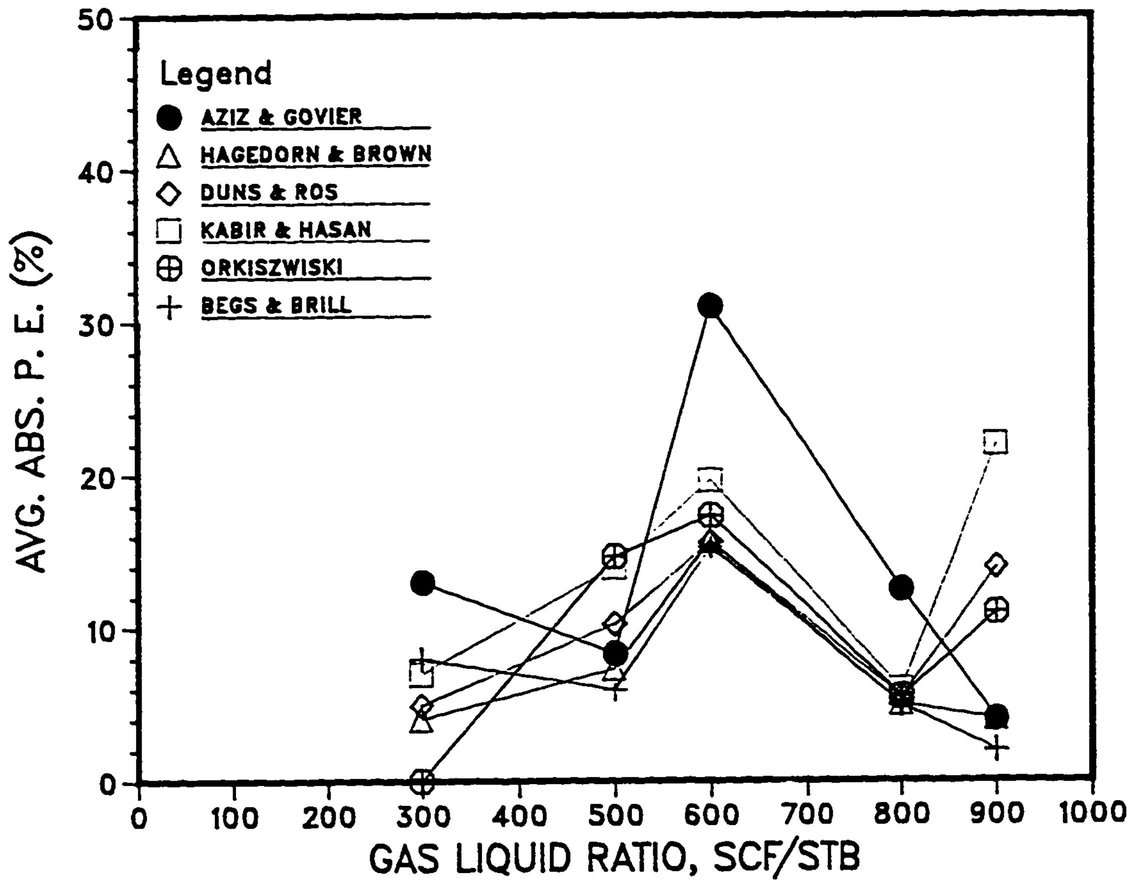


Fig. 3.27: Comparison of the Average Absolute Percent Error for all Correlations using 3.5 in. Tubing Size with Gas-Liquid Ratio as a Parameter.

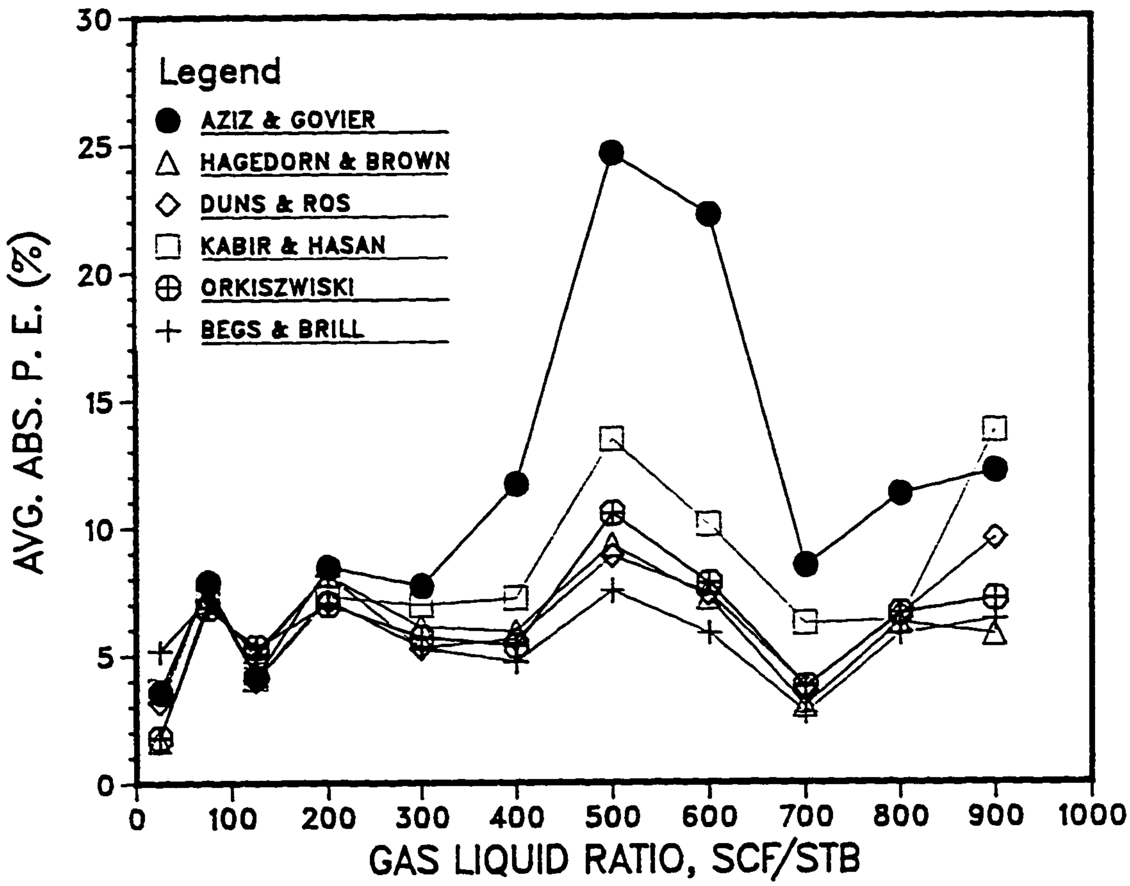


Fig. 3.28: Comparison of the Average Absolute Percent Error for all Correlations using 4.5 in. Tubing Size with Gas-Liquid Ratio as a Parameter.

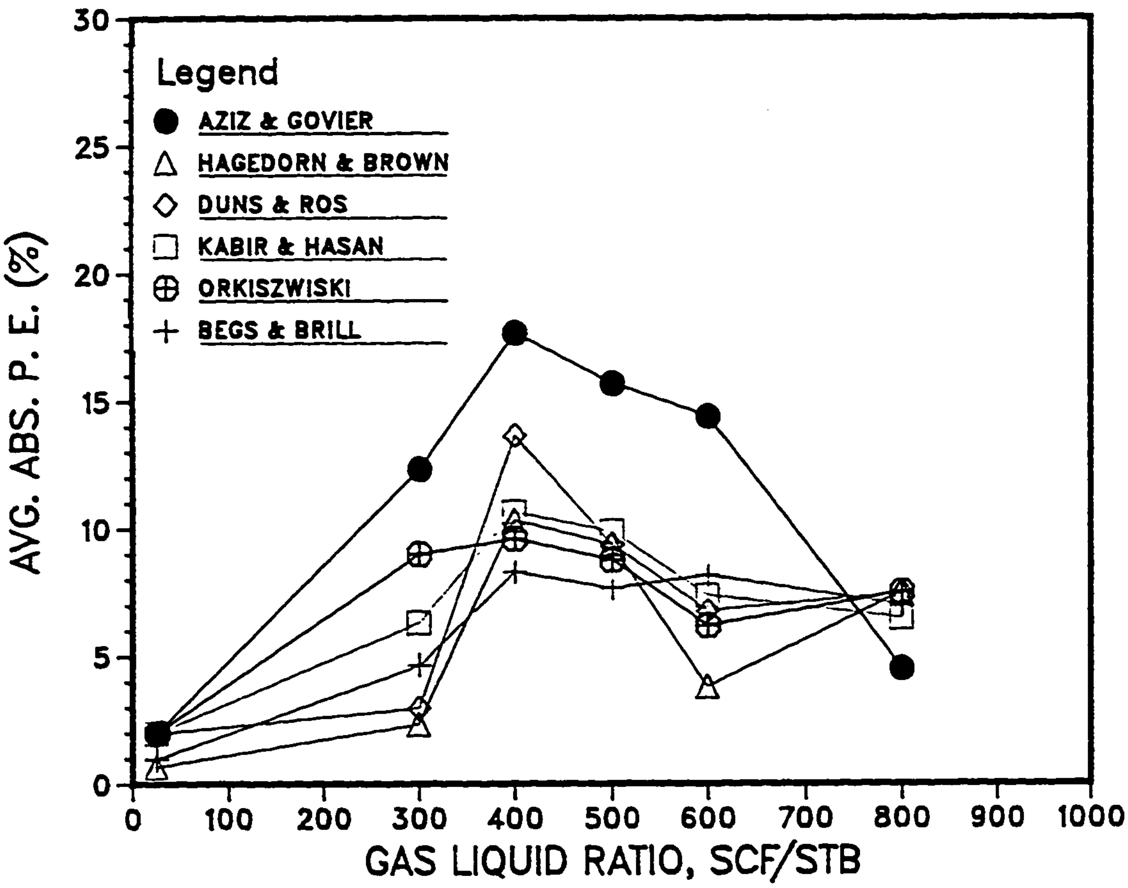


Fig. 3.29: Comparison of the Average Absolute Percent Error for all Correlations using 7 in. Tubing Size with Gas-Liquid Ratio as a Parameter.

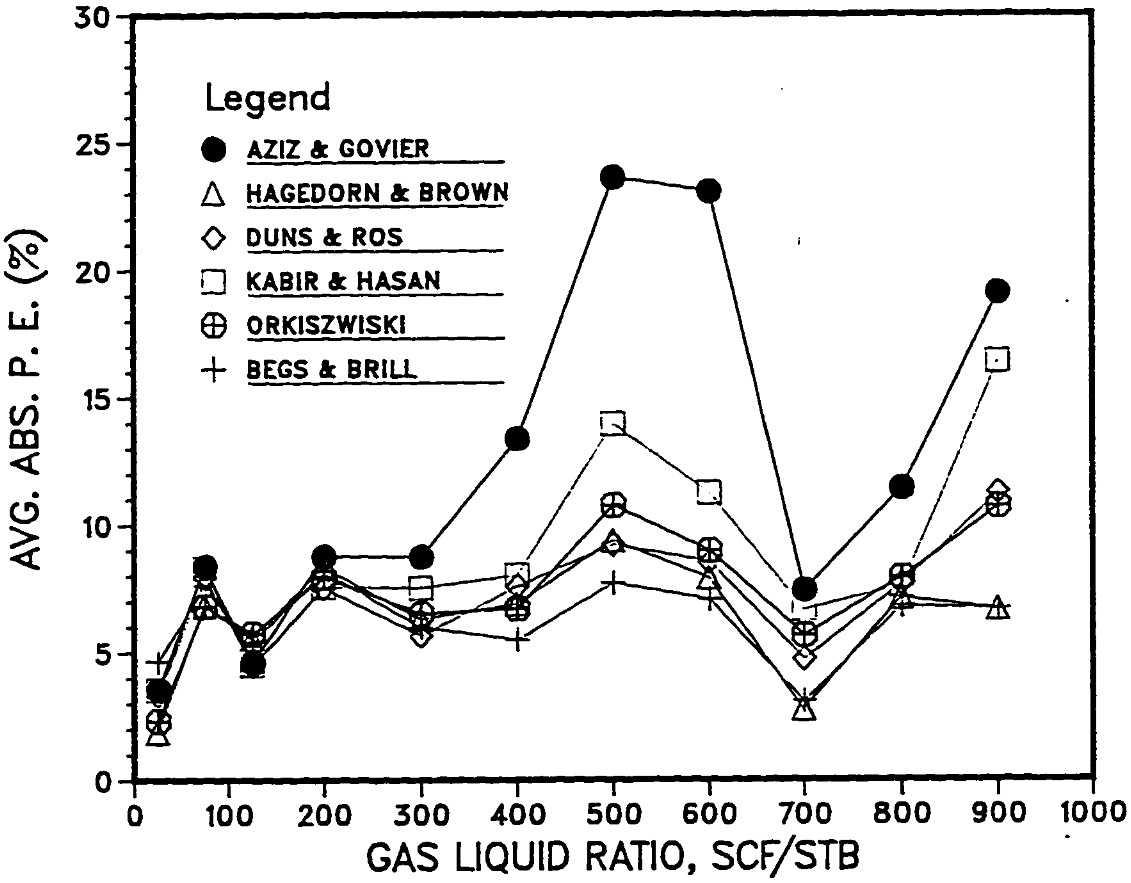


Fig. 3.30: Comparison of the Average Absolute Percent Error for all Correlations using data from all Tubings combined with Gas-Liquid Ratio as a Parameter.

SCF/STB, Beggs and Brill followed by Orkiszewski are superior to the rest of the correlations. For gas-liquid ratios between 550 SCF/STB and 650 SCF/STB, all the correlations, except Aziz and Govier correlation, are predicting the pressure drop with an average absolute percent error less than 10% error. For gas-liquid ratios greater than 650 SCF/STB, most of the correlations tend to predict the pressure drop within ± 10% average absolute percent error.

Investigation of Fig. 3.30 shows that for gas-liquid ratios less than 350 SCF/STB, all the correlations are predicting the pressure drop within an average absolute percent error of ± 10%. For gas-liquid ratios between 350 SCF/STB and 950 SCF/STB, the Beggs and Brill correlation followed by Hagedorn and Brown correlation are superior to the rest of the correlations. While Aziz and Govier correlation is the least accurate correlation.

3.5.2 Effect of Water Cut

The average absolute percent errors for all six correlations are plotted against the water cut percentage for the 2.375 in. and 2.875 in., 3.5 in. 4.5 in. and 7 in. tubings data points in Figs. 3.31, 3.32, 3.33 and 3.34 respectively. Figure 3.35 compares the errors calculated for all correlations using the data from all tubing combined.

Investigation of these figures shows that for 2.375 in., 2.875 in.,

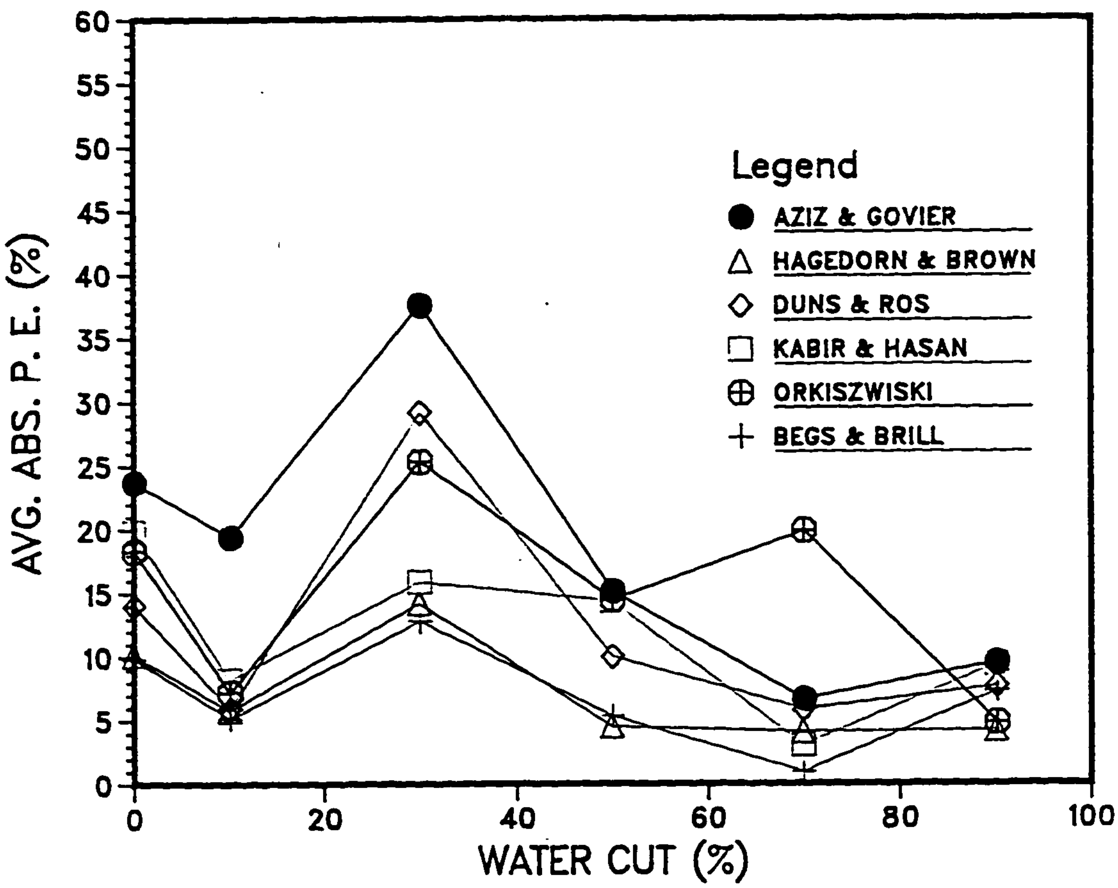


Fig. 3.31: Comparison of the Average Absolute Percent Error for all Correlations using 2.375 in. and 2.875 in Tubing Size with Water Cut as a Parameter.

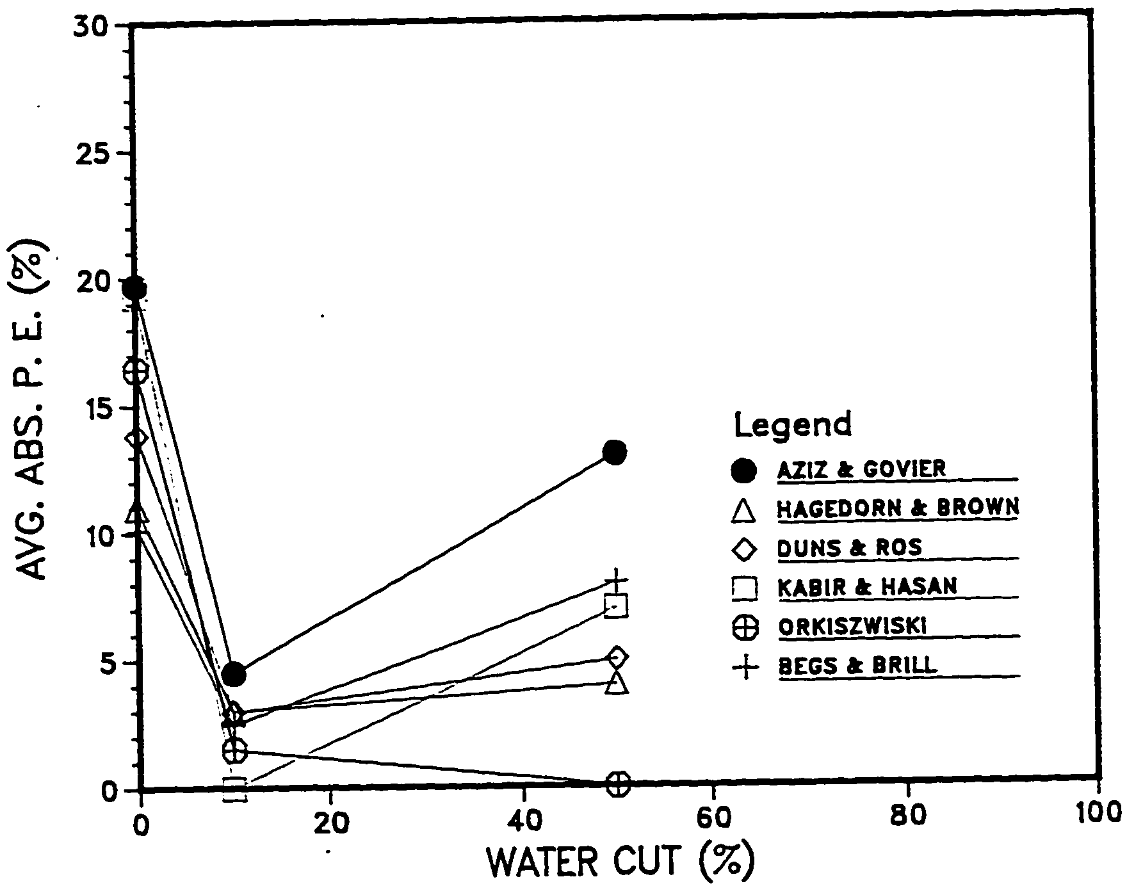


Fig. 3.32: Comparison of the Average Absolute Percent Error for all Correlations using 3.5 in. Tubing Size with Water Cut as a Parameter.

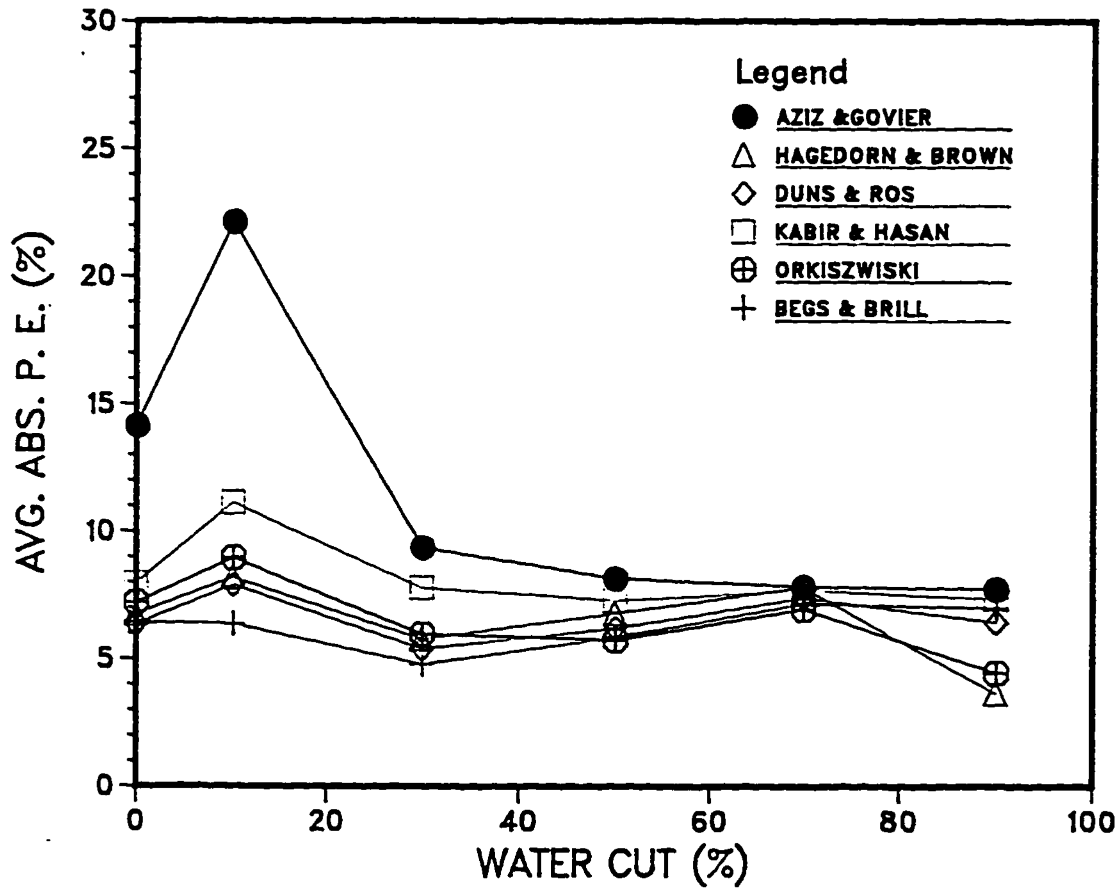


Fig. 3.33: Comparison of the Average Absolute Percent Error for all Correlations using 4.5 in. Tubing Size with Water Cut as a Parameter.

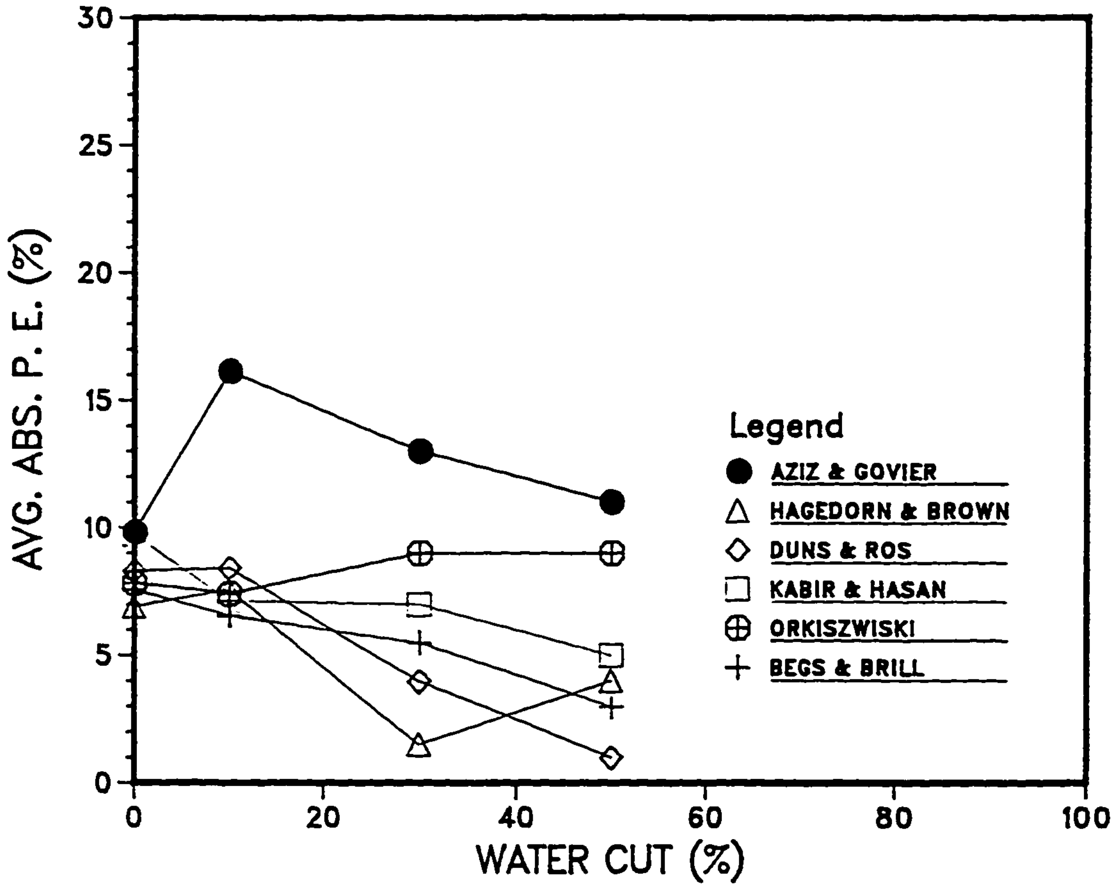


Fig. 3.34: Comparison of the Average Absolute Percent Error for all Correlations using 7 in. Tubing Size with Water Cut as a Parameter.

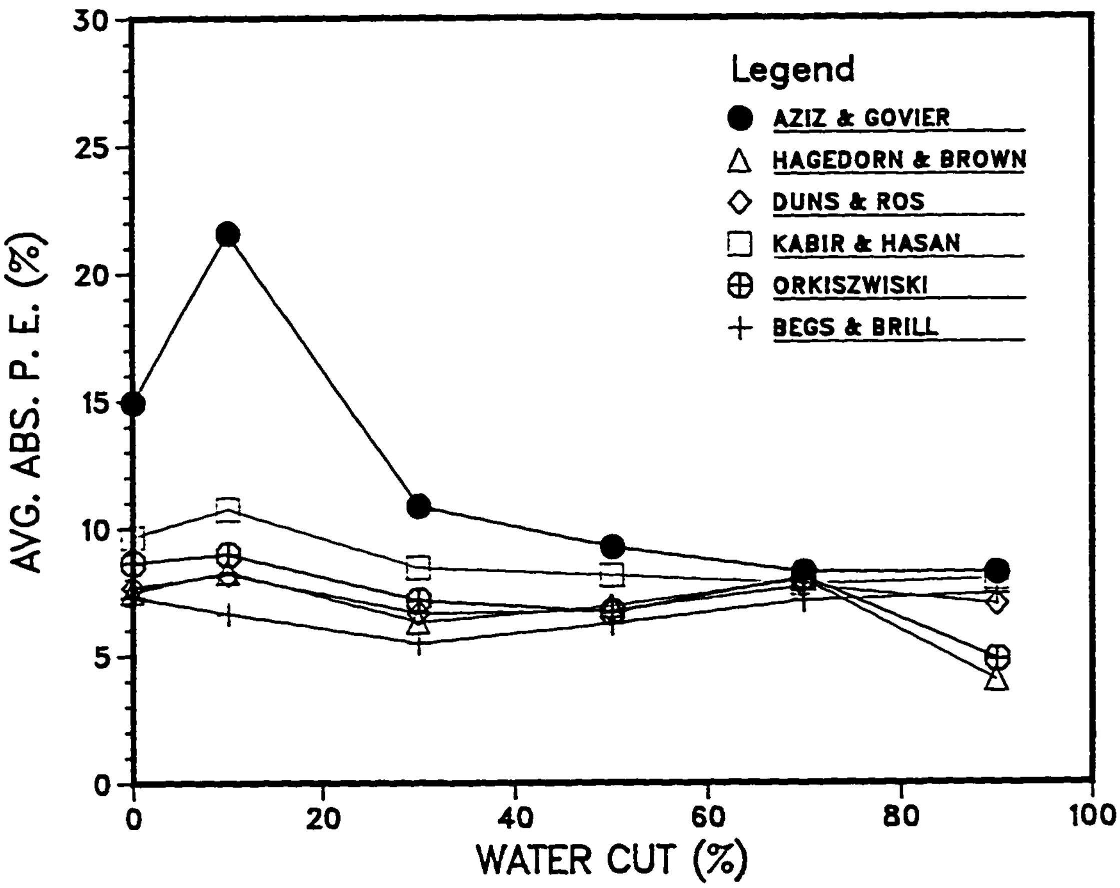


Fig. 3.35: Comparison of the Average Absolute Percent Error for all Correlations using data from all Tubings combined with Water Cut as a Parameter.

and 3.5 in. tubing, all the correlations, except Beggs and Brill, and Hagedorn and Brown correlations, tend to predict the pressure drop for zero water cut with an average absolute percent error higher than 11%. For the water cut higher than zero and less than 20%, all the correlations, except Aziz and Govier correlation, tend to predict the pressure drop with an average absolute percent error less than 10%, with the Beggs and Brill, and Hagedorn and Brown correlations being the best. Aziz and Govier correlation tends to predict the pressure drop for water cut between 20% and 60% with an average absolute percent error higher than 10%. It also shows that Hagedorn and Brown, and Beggs and Brill correlations are superior to the rest of the correlations. For the 4.5 in. tubing, almost all the correlations, except Aziz and Govier correlation, tend to predict the pressure drop with an average absolute perentt error less than 10%. Aziz and Govier correlation predicts the pressure drop for water cut percent less than 20% with an average absolute percent error more than 10%. It also shows that Hagedorn and Brown, and Orkiszewski correlations tend to predict better as the water cut increases (gas-liquid ratio decreases). For the 7 in. tubing, all the correlations, except Aziz and Govier correlation, tend to predict the pressure drop within an average absolute percent error of 10%. Hagedorn and Brown correlation is the best for data with water cut between 20% and 40%, while Duns and Ros correlation is the best correlation for data with water cut between 40% and 60%.

Investigation of Fig. 3.35 shows that all correlations, except Aziz and Govier correlation, tend to predict the pressure drop within an average absolute percent error less than 10%, with Beggs and Brill and Hagedorn and Brown being the best correlation for water cut less than 80%, and Hagedorn and Brown, and Orkiszewski correlations being the best for data with water cut higher than 80%.

3.5.3 Effect of Production Rate

The average absolute percent errors for the six correlations are plotted against the production rate for the different tubing sizes of 2.375 in. and 2.875 in., 3.5 in., 4.5 in. and 7 in. in Fig. 3.36, 3.37, 3.38 and 3.39 respectively. Also, Fig. 3.40 compares the errors calculated for all correlations using the data from all the tubings combined.

Investigation of these figures shows that for 2.375 in. and 2.875 in. tubings, only Hagedorn and Brown, and Beggs and Brill correlations predict the pressure for the liquid rate less than 5000 STB/day within an average absolute percent error less than 10%. While Aziz and Govier correlation being the least accurate one predict the pressure within an average absolute percent error higher than 20%, where, for the liquid rate between 5000 and 1000 STB/day, the accuracy of the Aziz and Govier, Kabir and Hasan, and Orkiszewski correlations improves. For the 3,5 in. tubing, the correlations, except Aziz and Govier

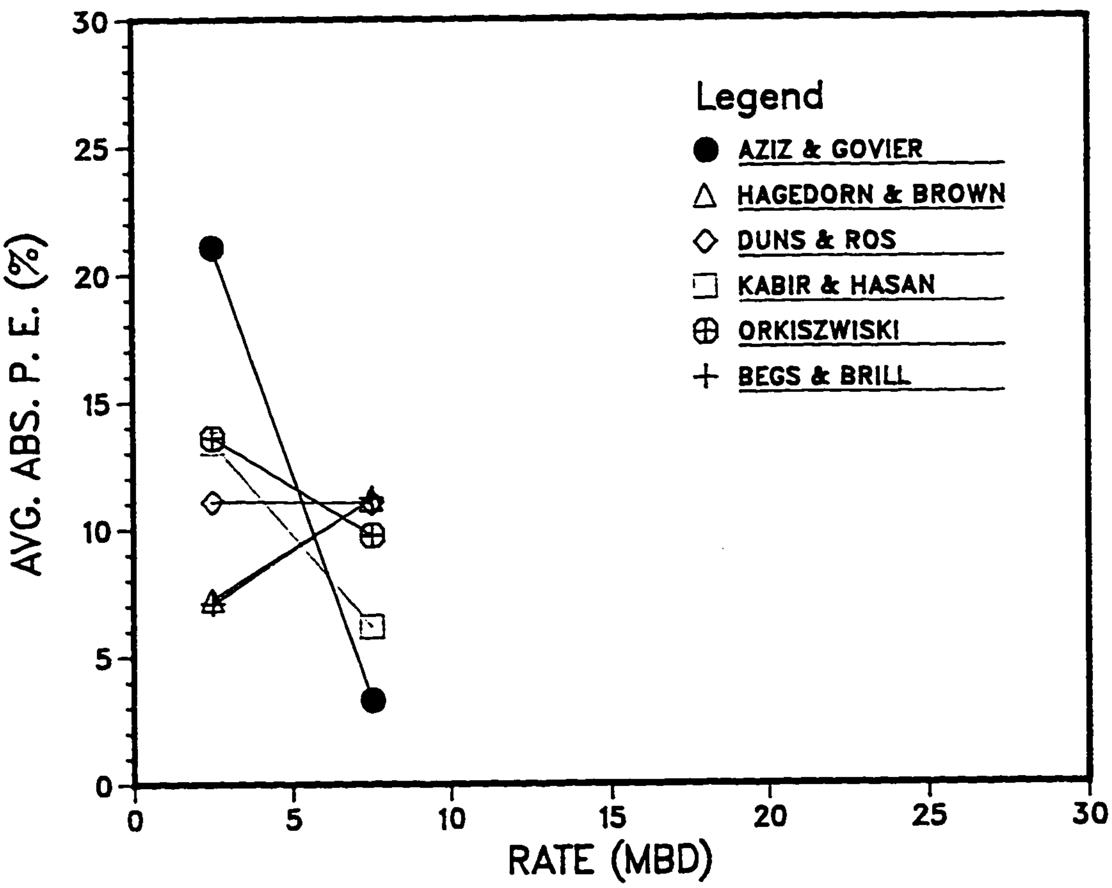


Fig. 3.36: Comparison of the Average Absolute Percent Error for all Correlations using 2.375 in. and 2.875 in Tubing Size with Liquid Rate as a Parameter.

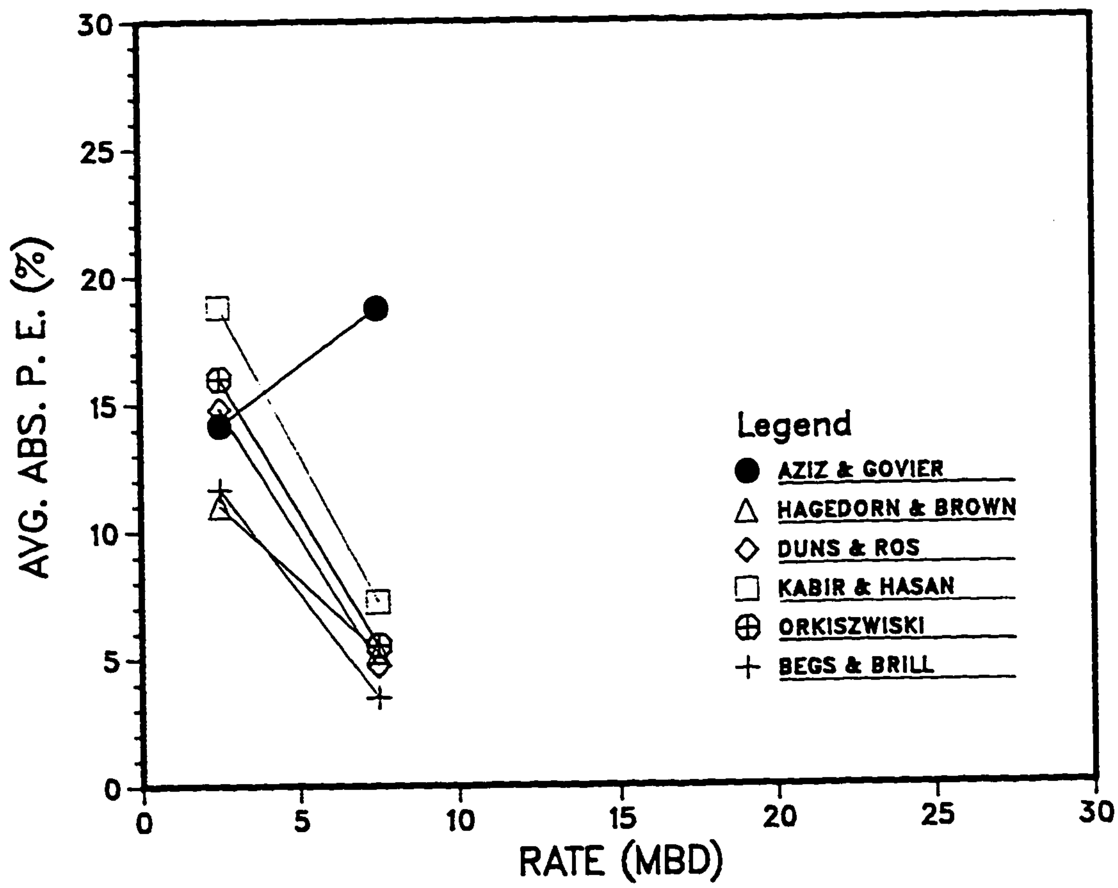


Fig. 3.37: Comparison of the Average Absolute Percent Error for all Correlations using 3.5 in. Tubing Size with Liquid Rate as a Parameter.

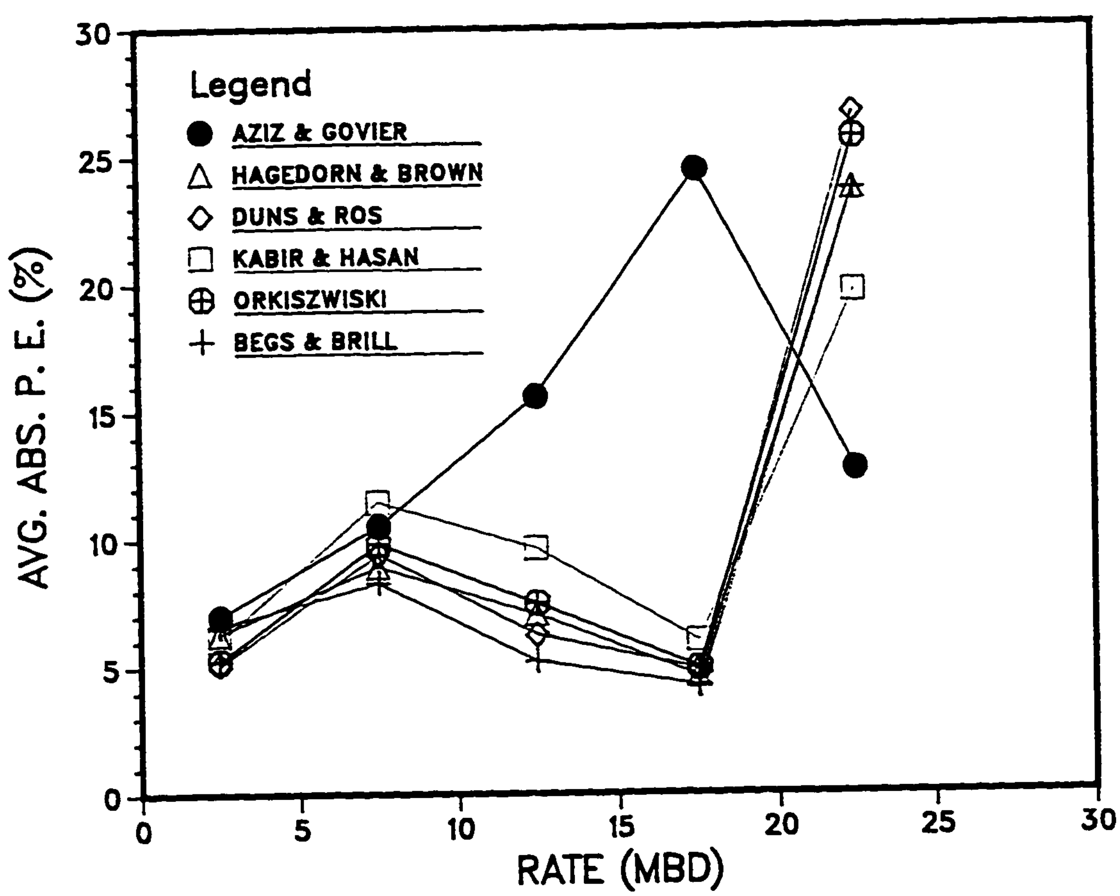


Fig. 3.38: Comparison of the Average Absolute Percent Error for all Correlations using 4.5 in. Tubing Size with Liquid Rate as a Parameter.

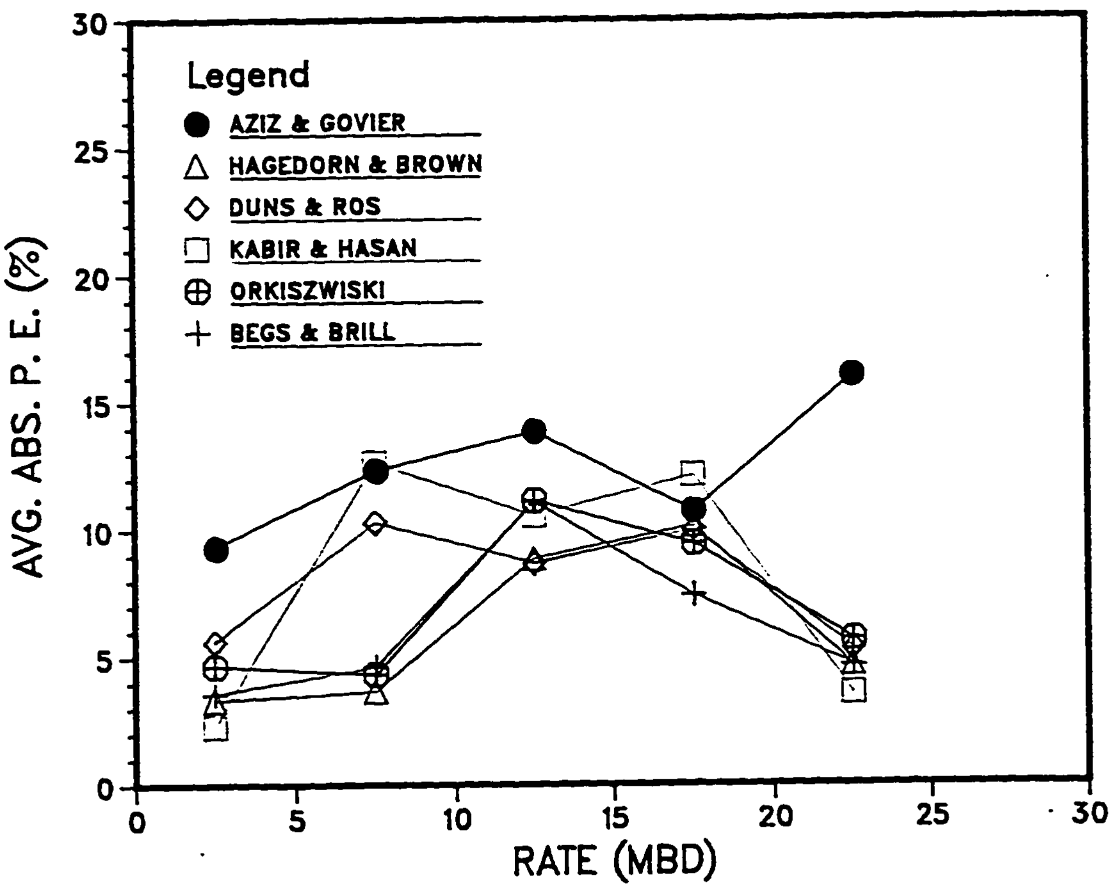


Fig. 3.39: Comparison of the Average Absolute Percent Error for all Correlations using 7 in. Tubing Size with Liquid Rate as a Parameter.

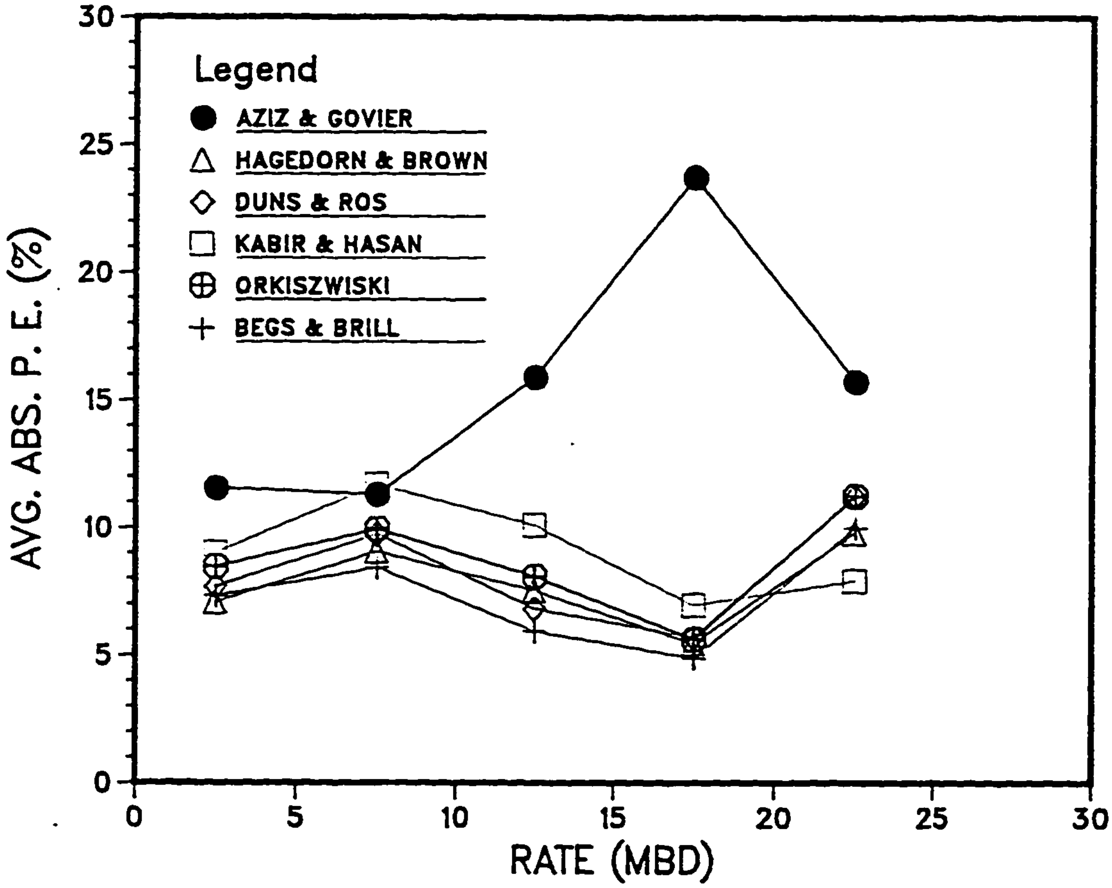


Fig. 3.40: Comparison of the Average Absolute Percent Error for all Correlations using data from all Tubings combined with Liquid Rate as a Parameter.

correlation, tend to predict the pressure better as the production rate increases. For the 4.5 in. tubing, all the correlations tend to predict the pressure drop for production rate less than 10,000 STB/day within an average absolute percent error, almost equal to 10%, and tend to give (except Aziz and Govier's) better predictions as the rate increase to 20,000 STB/day. For production rate between 20,000 and 25,000 STB/day, only Aziz and Govier correlation is predicting the pressure drop within an average absolute percent error almost equals to 12%, while the rest are predicting within an average absolute percent error higher than 18%. For the 7 in. tubing, all the correlations (except Aziz and Govier's) predict the pressure within an average absolute percent error almost equals to 10%. For the production rate between 5000 and 10000 STB/day, all the correlations, except Aziz and Govier's, are predicting the pressure within an average absolute percent error less than 5%. For production rate between 10,000 and 15,000 STB/day, Hagedorn and Brown, Orkiszewski, and Beggs and Brill correlations are predicting the pressure within an average percent error less than 5%. For the production rate between 15,000 and 20,000 STB/day, all the correlations predict the pressure within an average absolute percent error less than 12%, with the Beggs and Brill's correlation being the superior. For production rate between 20,000 and 25,000 STB/day, all the correlations, except Aziz and Govier correlation, are predicting the pressure within an average absolute percent error of 5%. The Kabirand Hasan correlation is the best.

Investigation of Fig. 3.40 shows that all the correlations, except Aziz and Govier correlation, predicts the pressure within an average absolute percent error less than 12%. Beggs and Brill and Hagedorn and Brown correlations are the best to predict the pressure drop from production rate less than 20,000 STB/day. Kabir and Hasan correlation is the best correlation to predict the pressure drop for wells producing more than 20,000 STB/day. It has an average absolute percent error less than 8%. Aziz and Govier correlation is having an average absolute percent error higher than 15%.

Table 3.27 shows the statistical analysis of all the data for the different correlations. It shows that, Beggs and Brill calculation is the best compared to all other correlations. For this correlation, 80% of the data lie within ± 10% error with an average absolute percent error, coefficient of variance and correlation coefficient of 6.72, 9.24 and 0.78 respectively indicating that the correlation is good in predicting the pressure drop. The table also shows that, using Aziz and Govier calculation method, only 45% of the data points are predicted with ± 10% error indicating that the correlation poorly predicts the flowing bottom hole pressures. The coefficient of variance and the correlation coefficient are 20.6 and zero indicating poor predictions. The table also indicates that Hagedorn and Brown, Duns and Ros, and Orkiszwiski correlations are predicting the flowing bottom hole pressures, of more than 70% of the data, within ± 10% error. The correlation coefficients for these correlations are 0.70, 0.68 and 0.62 respectively. This

Table 3.27: Statistical Analysis Results of All Correlations

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
Hagedorn and Brown	7.49	255	10.5	0.70	414	49%	74%	88%	95%	98%	100%
Aziz and Govier	15.5	500	20.6	0	414	28%	45%	60%	69%	77%	100%
Duns and Ros	7.60	260	10.7	0.68	414	48%	74%	88%	94%	96%	100%
Kabir and Hasan	9.59	313	12.9	0.48	414	36%	65%	80%	90%	93%	100%
Orkiszwiski	8.20	279	11.5	0.62	414	44%	70%	85%	93%	95%	100%
Beggs and Brill	6.72	224	9.24	0.78	414	51%	80%	91%	96%	97%	100%

indicates that these correlations are, in general, good correlations for predicting the pressure drop. Using Kabir and Hasan calculation method, only 65% of all the data points lie within ± 10% error. The coefficient of variance and the correlation coefficient are 12.9 and 0.48 respectively, indicating that the correlation provides reasonable prediction of pressure drop.

3.5.4 Effect of Tubing Size

Figure 3.41 compares the average absolute percent errors for all six correlations with the data divided according to tubing size.

Investigation of this figure shows that, in general, all the correlations tend to provide better prediction for the larger tubings. Beggs and Brill, and Hagedorn and Brown correlations provide the best predictions among all correlations; while Aziz and Govier correlation appears to be the least accurate.

Table 3.28 summarizes the results of the comparison. For the 2.375 in. and 2.875 in. tubings, Beggs and Brill, and Hagedorn and Brown correlations have average absolute percent errors less than 8%. The rest of the correlations have errors higher than 10% with the Aziz and Govier correlation having the highest APE (20%). For the 3.5 in. tubing, Beggs and Brill, and Hagedorn and Brown are predicting the pressure within an average absolute percent error of 10%. The rest of

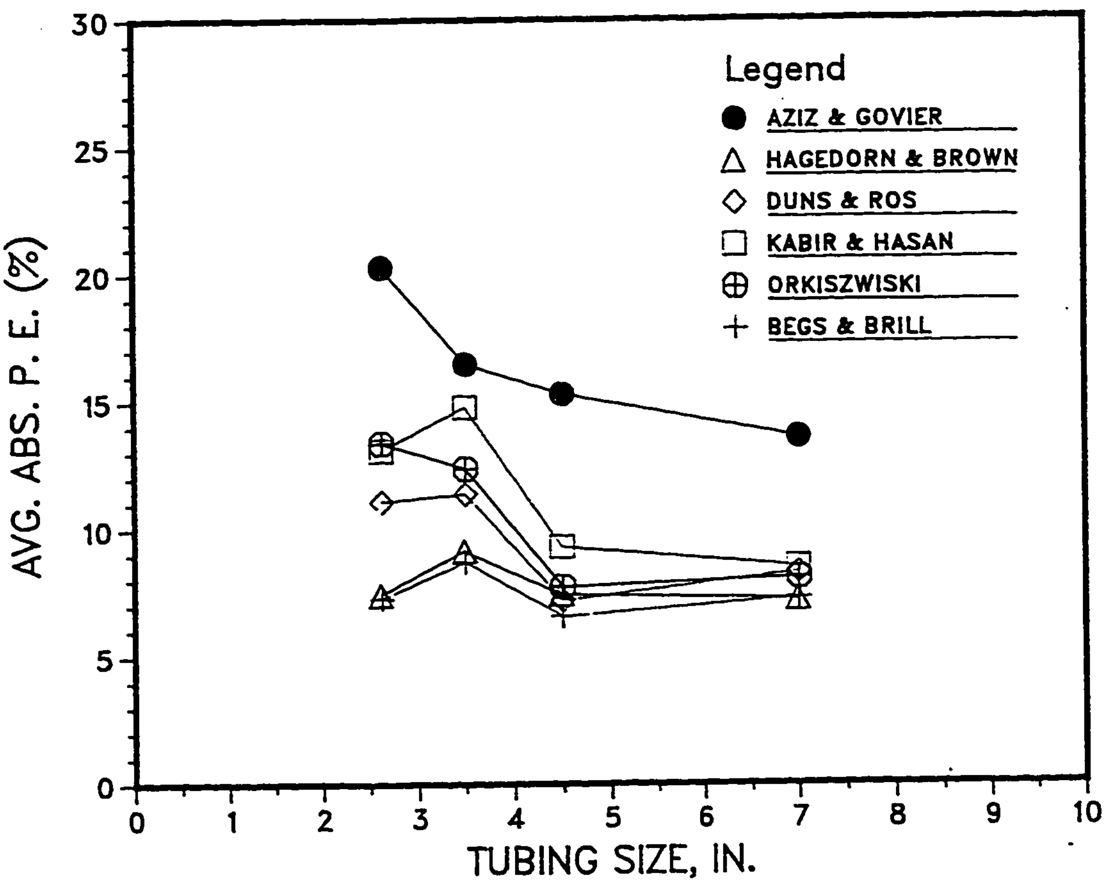


Fig. 3.41: Comparison of the Average Absolute Percent Error for all Correlations with the data divided according to Tubing Size.

Table 3.28: The Average Absolute Percent Error for Different Correlations with Tubing Size as a Parameter

Correlation	2.375 and 2.875 in.	3.5 in.	4.5 in.	7 in.
Hagedorn and Brown	7.43	9.15	7.42	7.22
Aziz and Govier	20.30	16.50	15.30	13.60
Duns and Ros	11.10	11.40	7.21	8.30
Kabir and Hasan	13.10	14.80	9.30	8.50
Orkiszewski	13.40	12.40	7.74	8.10
Beggs and Brill	7.30	8.73	6.58	7.30

the correlations predict the pressure with errors higher than 10%, with the Aziz and Govier correlation being the worst having an average absolute percent error of 16%. For tubing size 4-1/2" tubing, all the correlations, except Aziz and Govier correlation, are predicting the pressure with average absolute percent errors less than 10%. Aziz and Govier correlation has an average absolute percent error greater than 15%. For the 7" tubing, all the correlations, except Aziz and Govier correlations predict the pressure within an average absolute percent error of 10% with Beggs and Brill, and Hagedorn and Brown correlations being the best.

3.6 Modification of Some Correlations

All previously discussed correlations, except that of Hagedorn and Brown, use some flow-pattern transition criteria for determining the flow pattern and consequently employ the correct pressure drop calculation. Several flow pattern maps were developed after most of these correlations were published. Among those, the flow pattern maps of Weisman and Kang [50] and of Dukler [15] are claimed to be the best for they were developed using some theoretical basis.

In the present study, each of the original correlations have been compared against the modified versions using the flow-pattern maps of Wiseman and Kangs, and Dukler. The correlations of Aziz and Govier was further compared against modified versions using the flow pattern transition criteria of Duns and Ros, and Orkiszewski. The results of the comparisons are shown in Figs. 3.42, 3.43, 3.44, 3.45 and 3.46 for the correlations of Duns and Ros, Kabir and Hasan, Orkiszewski, Beggs and Brill, and Aziz and Govier respectively.

Investigation of these figures show that neither Dukler or Weiseman and Kang flow-pattern map offers any improvement over any of the original correlations. The correlation of Aziz and Gover, however, was greatly improved by employing the flow-pattern transition criteria of Duns and Ros or Orkiszewski. The improvement is more noticeable for higher gas-liquid ratios. Table 3.30 illustrates the improvement of Aziz and Govier correlation.

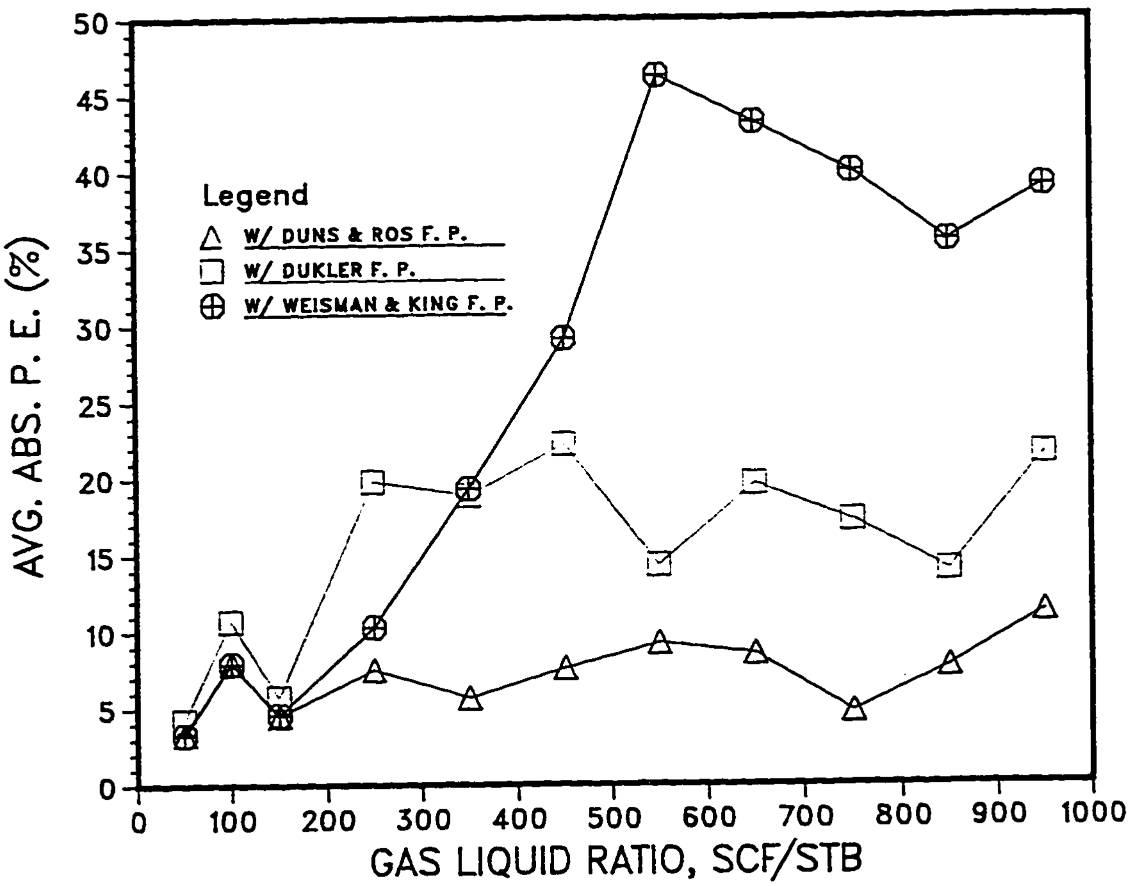


Fig. 3.42: Comparison of the Average Absolute Percent Error for Duns and Ros Correlation using different Flow Patterns with Gas-Liquid Ratio as a Parameter.

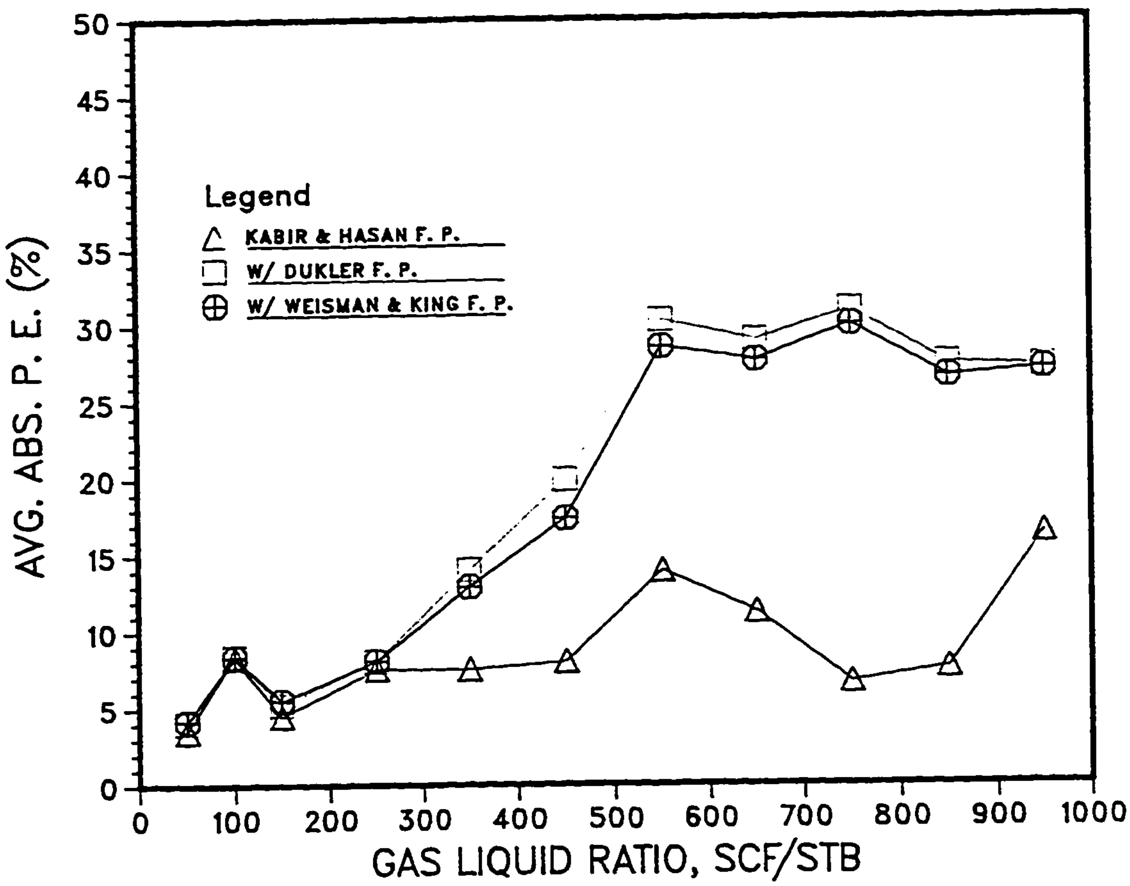


Fig. 3.43: Comparison of the Average Absolute Percent Error for Kabir and Hasan Correlation using different Flow Patterns with Gas-Liquid Ratio as a Parameter.

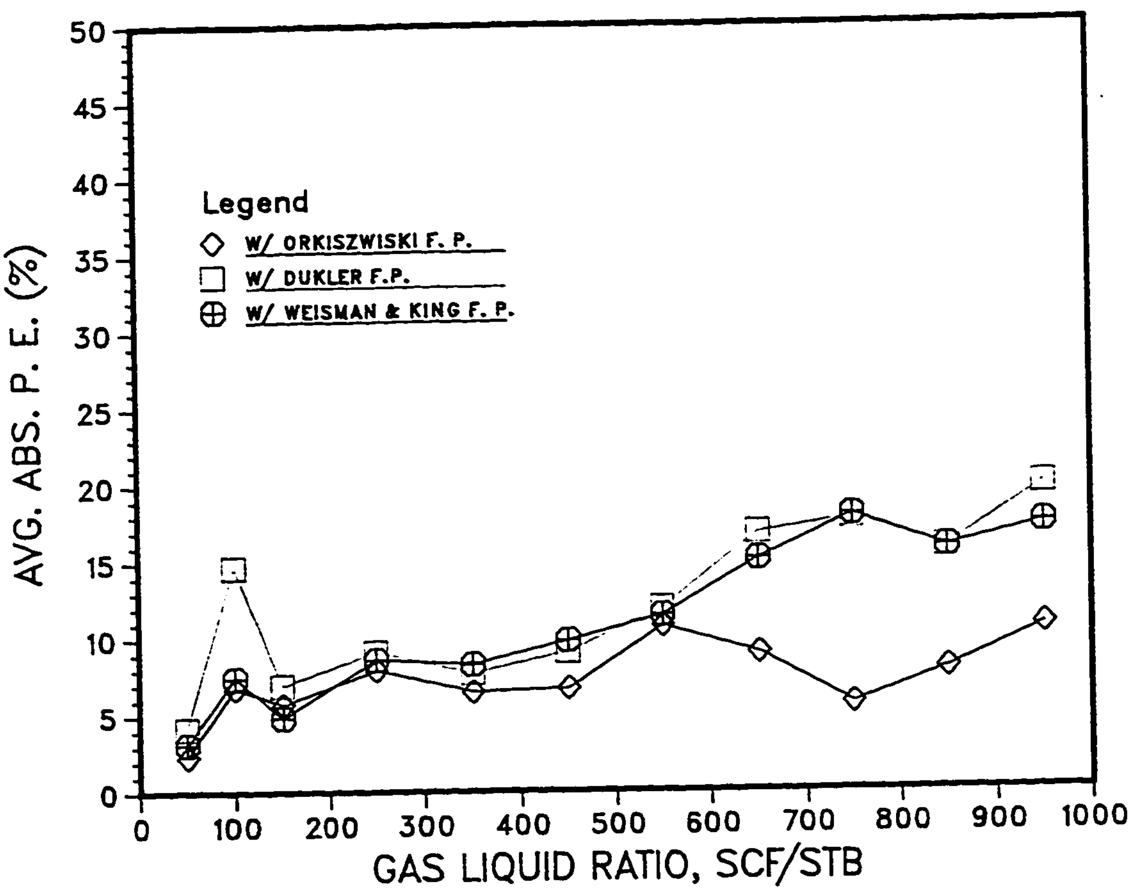


Fig. 3.44: Comparison of the Average Absolute Percent Error for Orkiszewski Correlation using different Flow Patterns with Gas-Liquid Ratio as a Parameter.

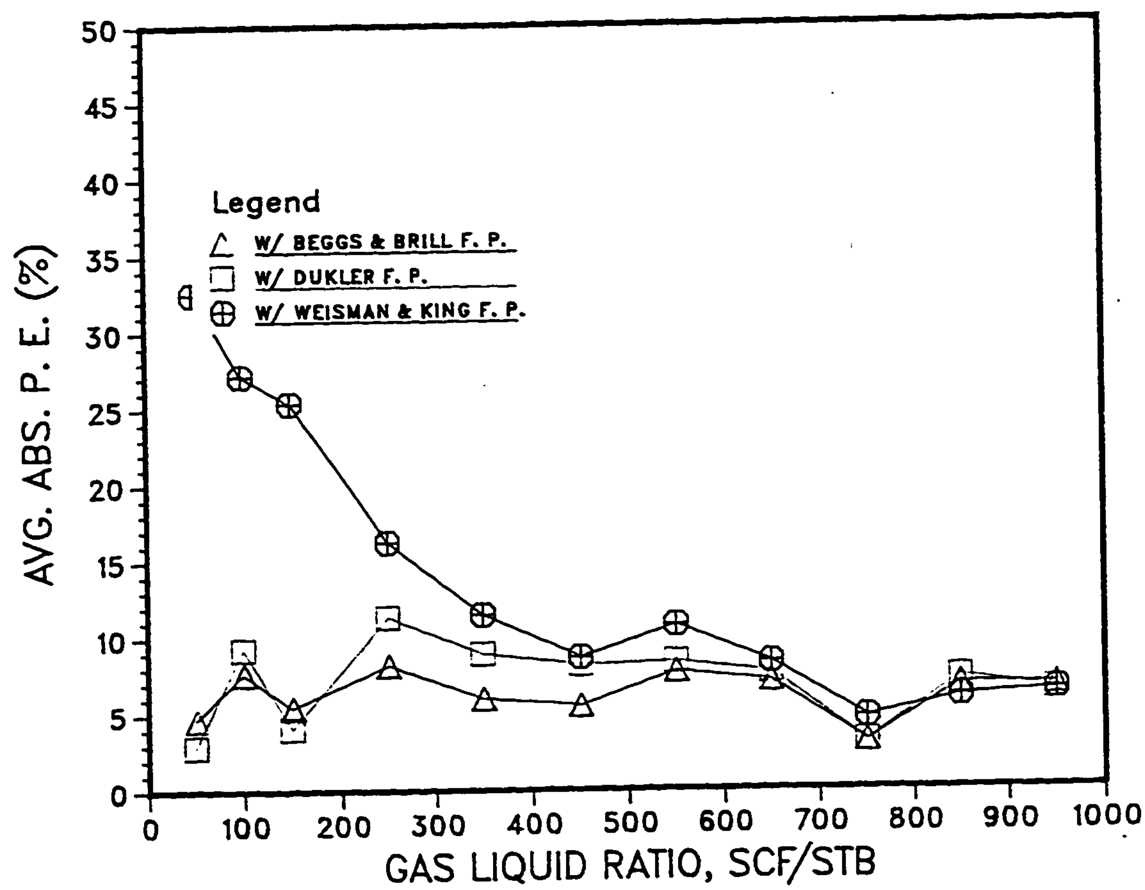


Fig. 3.45: Comparison of the Average Absolute Percent Error for Beggs and Brill Correlation using different Flow Patterns with Gas-Liquid Ratio as a Parameter.

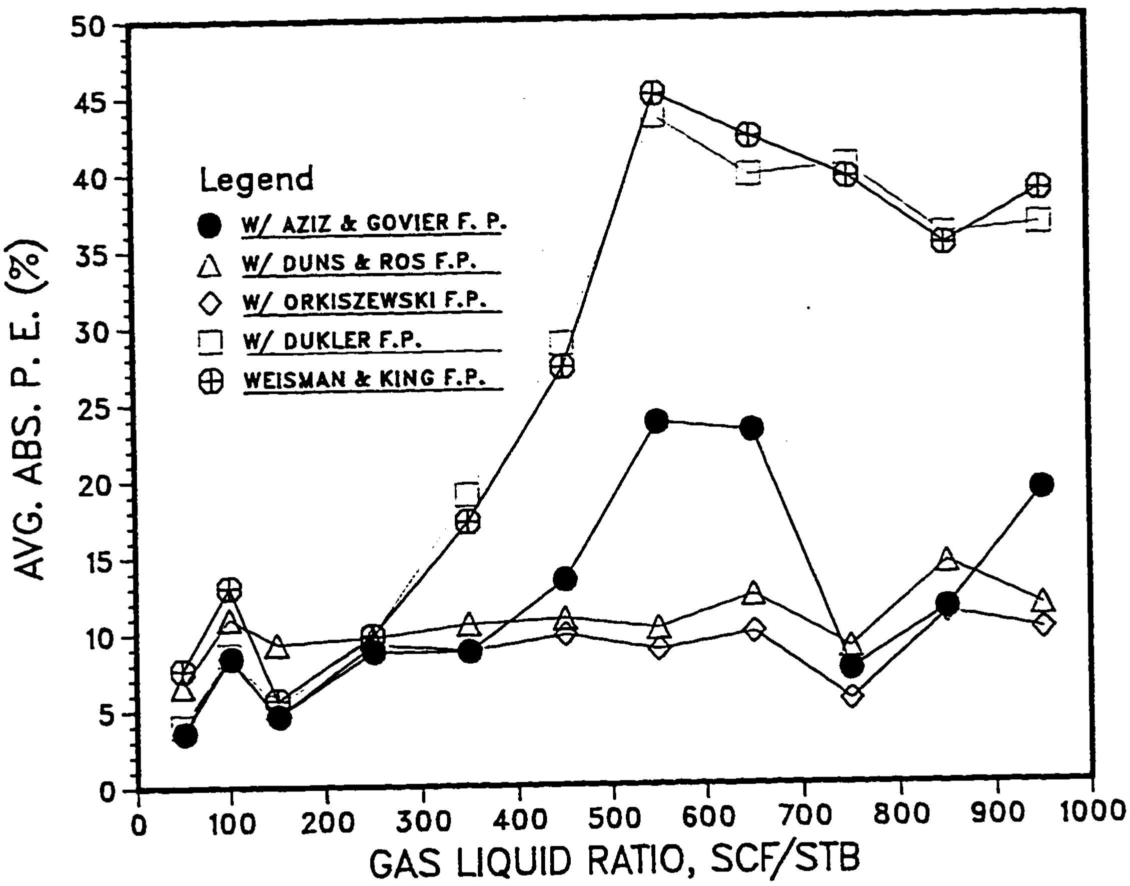


Fig. 3.46: Comparison of the Average Absolute Percent Error for Aziz and Govier Correlation using different Flow Patterns with Gas-Liquid Ratio as a Parameter.

Table 3.29: Statistical Analysis of Aziz and Govier Calculation Method Using Different Flow Patterns

Condition	AAPE	SD	CV	r	Number of Data Points (% of total) lying in the specified range of deviation						
					Points	+ 5%	+ 10%	+ 15%	+ 20%	+ 25%	+ > 25%
w/Aziz & Govier F.P.	15.5	500	20.6	0	414	28%	45%	60%	69%	77%	100%
w/Dukler F.P.	29.6	865	35.6	0	414	13%	23%	27%	33%	40%	100%
w/Weisman & King F.P.	30.3	901	37.2	0	414	12%	22%	30%	37%	43%	100%
w/Duns & Ros F.P.	10.8	336	13.8	0.34	414	30%	55%	75%	87%	95%	100%
w/Orkiszwiski F.P.	8.70	262	10.8	0.68	414	36%	66%	85%	92%	97%	100%

CHAPTER 4

SUMMARY AND CONCLUSIONS

Chapter 4

SUMMARY AND CONCLUSIONS

1. Computer programs were prepared to implement six vertical multiphase flow correlations for predicting the pressure drop.

2. Statistical analysis has been performed to evaluate the existing correlation against 414 data points collected from Saudi Arabian oil fields.

3. No single correlation was found to predict the pressure drop with good accuracy for all ranges of variables.

4. Hagedorn and Brown correlation is found to be the best correlation to predict the pressure drop for wells producing with more that 80% water cut.

5. Kabir and Hasan correlation is found to be the best correlation to predict the pressure drop for wells producing more than 20,000 STB/day total fluid.

6. Beggs and Brill correlation followed by Hagedorn and Brown correlation are found to be the best of the six correlations considering all the present data.

7. Implementation of Dukler, Weisman and Kang flow pattern transition criteria did not provide any improvement over the existing original correlation.

8. Aziz and Govier correlation was greatly improved by implementation of Duns and Ros F.P. and Orkiszewski F.P.

NOMENCLATURE

A_p = pipe cross-sectional area, ft^2 (m^2)

C = proportionality factor

C_o = distribution coefficient

d = inside tubing diamter, ft (m)

E_g = void fraction

f = funning friction factor

F_1 = dimensionless group

F_2 = dimensionless group

F_3 = dimensionless group

F_4 = dimensionless group

F_5 = dimensionless group

F_6 = dimensionless group

F_7 = dimensionless group

g = gravitational acceleration, ft/sec^2 (m/sec^2)

g_c = dimension conversion factor = 32.2 lbm ft/lbf sec^2

H_L = holdup

$H_L(\varphi)$ = two phase density

ε/d = relative roughness of pipe

L_1 = dimensionless group

L_2 = dimensionless group

L_3 = dimensionless group

L_4 = dimensionless group

L_b = bubble-slug boundary, dimensionless

L_m = transition-mist boundary, dimensionless

L_s = slug-transition boundary, dimensionless

N_b = bubble Reynolds number, dimensionless

N_d = pipe diameter number

NE = Eotvos number

N_{FR} = Froude number

N_{gv} = gas velocity number

N_L = liquid viscosity number

N_{Lv} = liquid velocity number

NV = Wallis liquid viscosity number

P = average pressure, psi

ΔP = pressure drop, psi

q_g = gas rate, ft^3/sec (m^3/sec)

q_L = liquid rate, ft^3/sec (m^3/sec)

q_t = total liquid rate, ft^3/sec (m^3/sec)

R_e = Reynolds number

S = slip factor

V = insitu velocity of any given phase, ft/sec (m/sec)

V_{bf} = bubble rise velicity in the flowing stream, ft/sec (m/sec)

V_{bs} = bubble rise velocity under stagnant condition, ft/sec (m/sec)

V_{gd} = dimensionless gas velocity

V_m = mixture superfacial velocity, ft/sec (m/sec)

V_s = slippage velolcity, ft/sec (m/sec)

V_{sb} = bubble rise velocity, ft/sec (m/sec)

V_{sg} = gas superfacial velocity, ft/sec (m/sec)

V_{sL} = liquid superfacial velocity, ft/sec (m/sec)

V_t = terminal rise velocity of a single bubble, ft/sec (m/sec)

V_{tT} = terminal rise velocity of a single Taylor bubble (in slug flow), ft/sec (m/sec)

W_t = total mass flow rate, lb/sec

ΔP_f = friction component of ΔP, psi

ΔZ = depth increment

ΔP_s = static component of ΔP, psi

λ_L = lambda

μ = viscosity, lbm/sec.ft

μ_L = liquid viscosity, lbm/sec.ft

μ_g = gas viscosity, lbm/sec.ft

ρ = average fluid density, lbm/ft^3 (kg/m^3)

ρ_g = gas density, lbm/ft^3 (kg/m^3)

ρ_L = liquid density, lbm/ft^3 (kg/m^3)

ρ_m = mixture density, lbm/ft^3 (kg/m^3)

σ_g = gas interfacial tension, lbm/sec^2 (kg/sec^2)

σ_L = liquid interfacial tension, lbm/sec^2 (kg/sec^2)

τ_f = the wall friction-loss term, lbm/ft^2/ft

Subscripts

a = atmospheric

acc = acceleration

b = bubble

d = dimensionless

ele = elevation

f = friction

FR = Froude

g = gas

L = liquid

m = mixture

n = no slip

o = oil

APPENDICES

s = superficial

st = static

t = total

tp = two-phase

TOT = total

v = velocity

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APPENDIX A

PROGRAM LISTING

```
C
C
C     HAGEDORN & BROWN CORRELATION
C
C
C     H & B
      SUBROUTINE HB(VS,RESTMP,SURTMP,P1,DEPTH1,OILRTE,WTRRTE,DIMTB,
     &API,GOR,DIMTSG,DIMTBG,SPGWTR,SPGGAS,STNOIL,STNWTR,BW,EE,
     &DELP,DELTAH,G,GC,T1,TOTDEP,DIMTB2,DEPTB2,BHFP,IPROF)
C
      DEPTH1=0.
C
C     STEP : 1 CALCULATE SPECIFIC GRAVITY OF OIL
C
      SPGOIL=141.5/(131.5+API)
C     WRITE (6,101) SPGOIL
  101 FORMAT(T10,' SPGOIL =',T17,F10.5)
C     STEP : 2 CALCULATE GLR WOR WCUT TOTAL LIQUID AND FLUID GRADIENT
C
C     CALCULATE THE GAS LIQUID RATIO
C
      GLR=GOR*(OILRTE/(OILRTE+WTRRTE))
C     WRITE (6,102) GLR
102   FORMAT(T10,' GLR =',T17,F10.5)
C
C     CALCULATE THE WATER OIL RATIO
C
      WOR=WTRRTE/OILRTE
C     WRITE (6,103) WOR
103   FORMAT(T10,' WOR =',T17,F10.5)
C
C     CALCULATE THE WATER CUT
C
      WCUT=WTRRTE/(OILRTE+WTRRTE)
C     WRITE (6,104) WCUT
104   FORMAT(T10,' WCUT =',T17,F10.5)
C
C     CALCULATE THE TOTAL LIQUID
C
      TOTLIQ=OILRTE+WTRRTE
C     WRITE (6,105) TOTLIQ
105   FORMAT(T10,' TOTLIQ =',T17,F10.1)
C
C     CALCULATE FLUID GRADIENT
C
      APRXGD=.433*WCUT+SPGOIL*.433*(1.0-WCUT)
C     WRITE (6,106) APRXGD
106   FORMAT(T10,' APRXGD =',T17,F10.5)
C     STEP : 4 CALCULATE MASS ASSOCIATED WITH 1 STB OF LIQUID
      AMASS=((SPGOIL*350.0)*(1.0-WCUT))
      BMASS=SPGWTR*350.0*WCUT
```

```
      CMASS=0.0764*GLR*SPGGAS
      TM=AMASS+BMASS+CMASS
C     WRITE (6,108) TM
108   FORMAT(T10,' TM    =',T17,F10.5)
C
C     STEP : 5 CALCULATE MASS FLOW RATE
C
      W1=TM*TOTLIQ
C     WRITE (6,109) W1
109   FORMAT(T10,' W1    =',T17,F10.0)
C
C     STEP : 6 CALCULATE TEMPERATURE GRADIENT
C
      TEMGRD=(RESTMP-SURTMP)/TOTDEP
C     WRITE (6,110) TEMGRD
110   FORMAT(T10,' TEMGRD=',T17,F10.5)
C     WRITE (6,111) T1
111   FORMAT(T10,' T1     =',T17,F10.5)
C
C     STEP : 7 CALCULATE AVERAGE TEMP AND AVERAGE PRESS
C
11    DELP=DELTAH*APRXGD
      ITER=0
      DELTAH=50.
      DELP=25.
      GO TO 1001
C     STEP : 3 CALCULATE HYDRAULIC DIAMETER
C              DIMTSG: INSIDE DIAMETER OF THE CASING
C              DIMTBG: OUTSIDE DIAMETER OF THE TUBING
C              DIMTB : INSIDE DIAMETER OF THE TUBING
C     CALCULATE THE AREA OF FLOW
1000  DELP=DELPP
1001  IF(DIMTSG.EQ.0.0) GO TO 12
C
      AREA=(22/7)*((DIMTSG**2-DIMTBG**2)/4)
C
      GO TO 14
12    IF(DEPTH1.LE.DEPTB2) GO TO 938
      DIAM=DIMTB2
      GO TO 14001
938   DIAM=DIMTB
14001 AREA=22*DIAM**2/(4*7)
14    CONTINUE
C     WRITE (6,112) DELDEP
112   FORMAT(T10,' DELDEP=',T17,F10.5)
      T2=T1+TEMGRD*DELDEP
C     WRITE (6,113) T2
113   FORMAT(T10,' T2     =',T17,F10.5)
13    TAVG=(T1+T2)/2
C     WRITE (6,114) TAVG
114   FORMAT(T10,' TAVG  =',T17,F10.5)
```

```
      P2=P1+DELP
C     WRITE (6,115) P2
115   FORMAT(T10,' P2    =',T17,F10.5)
C     WRITE (6,116) P1
116   FORMAT(T10,' P1    =',T17,F10.5)
C
C     CALCULATE THE AVERAGE PRESSURE
C
      PAVG=(P1+P2)/2+14.7
C     WRITE (6,117) PAVG
117   FORMAT(T10,' PAVG  =',T17,F10.5)
C
C     STEP : 8 CALCULATE SOLUTION GAS AT AVGP P1 P2
C
19    X1=PAVG/18
      X2=(10**((.0125*(API))-(0.00091*TAVG)))
      X3=(((X1*X2))**(1/0.83))
      RSAVG=SPGGAS*X3
      IF(RSAVG.LE.GOR) GO TO 1111
      RSAVG=GOR
C111  WRITE (6,118) RSAVG
118   FORMAT(T10,' RSAVG =',T17,F10.5)
C     P1
1111  X5=P1/18
      X6=(10**((.0125*(API))-(0.00091*T1)))
      X7=(((X5*X6))**(1/0.83))
      RS1=SPGGAS*X7
      IF(RS1.LE.GOR) GO TO 20
      RS1=GOR
C     WRITE (6,119) RS1
119   FORMAT(T10,' RS1   =',T17,F10.5)
C     P2
20    X9=P2/18
      X10=(10**((.0125*(API))-(0.00091*T2)))
      X11=(((X9*X10))**(1/0.83))
      RS2=SPGGAS*X11
      IF(RS2.LE.GOR) GO TO 21
      RS2=GOR
C     WRITE (6,120) RS2
120   FORMAT(T10,' RS2   =',T17,F10.5)
21    CONTINUE
C
C     STEP : 9 CALCULATE FORM. VOL. FACTOR AT PAVG,TAVG P1,T1 P2,T2
C
      FAVG=((RSAVG*((SPGGAS/SPGOIL)**0.5))+(1.25*TAVG))
      BOAVG=(0.972+((0.000147)*((FAVG**1.175))))
C     WRITE (6,121) BOAVG
121   FORMAT(T10,' BOAVG =',T17,F10.5)
      F1=((RS1*((SPGGAS/SPGOIL)**0.5))+(1.25*T1))
      BO1=(0.972+((0.000147)*((F1**1.175))))
C     WRITE (6,122) BO1
```

```
122   FORMAT(T10,' BO1   =',T17,F10.5)
      F2=((RS2*((SPGGAS/SPGOIL)**0.5))+(1.25*T2))
      BO2=(0.972+((0.000147)*((F2**1.175))))
C     WRITE (6,123) BO2
123   FORMAT(T10,' BO2   =',T17,F10.5)
C
C     STEP : 10 CALCULATE THE DENSITY OF THE LIQUID PHASE
C
      G1=(SPGOIL*(62.4)+(RSAVG*SPGGAS*(0.0764))/(5.614))
      G2=((G1/BOAVG)*(1-WCUT))
      G3=((SPGWTR)*(62.4)*(WCUT))
      XLDEN=(G2+G3)
C     WRITE (6,124) XLDEN
124   FORMAT(T10,'XLDEN  =',T17,F10.5)
C     AT P1
      G4=(SPGOIL*(62.4)+(RS1*SPGGAS*(0.0764))/(5.614))
      G5=((G4/BO1)*(1-WCUT))
      G6=((SPGWTR)*(62.4)*(WCUT))
      DEN1=(G5+G6)
C     WRITE (6,125) DEN1
125   FORMAT(T10,' DFN1  =',T17,F10.5)
C     AT P2
      G7=(SPGOIL*(62.4)+(RS2*SPGGAS*(0.0764))/(5.614))
      G8=((G7/BO2)*(1-WCUT))
      G9=((SPGWTR)*(62.4)*(WCUT))
      DEN2=(G8+G9)
C     WRITE (6,126) DEN2
126   FORMAT(T10,' DEN2  =',T17,F10.5)
C
C     CALCULATE GAS COMPRESSIBILITY FACTOR AT PAVG,TAVG P1,T1 P2,T2
C
      PPC=(709.604-58.718*(SPGGAS))
      TPC=(170.491+307.344*(SPGGAS))
      APR=PAVG/PPC
      ATR=(TAVG+460)/TPC
      PR1=(P1+14.7)/PPC
      TR1=(T1+460)/TPC
      PR2=(P2+14.7)/PPC
      TR2=(T2+460)/TPC
C     COEFFICIENTS
      A1=0.31506237
      A2=-1.04670990
      A3=-0.57832729
      A4=0.53530771
      A5=-0.61232032
      A6=-0.10488813
      A7=0.68157001
      A8=0.68446549
C     AT PAVG TAVG  ASSUME Z=1.0
      PR=APR
      TR=ATR
```

```
      AZ=1.0
15    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 30
      AZ=CZ
      GO TO 15
30    AVGZ=CZ
C     WRITE (6,127) AVGZ
127   FORMAT(T10,' AVGZ  =',T17,F10.5)
C     AT P1 T1
      PR=PR1
      TR=TR1
      AZ=1.0
25    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 35
      AZ=CZ
      GO TO 25
35    Z1=CZ
C     WRITE (6,128) Z1
128   FORMAT(T10,' Z1    =',T17,F10.5)
C     AT P2 T2
      PR=PR2
      TR=TR2
      AZ=1.0
45    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 40
      AZ=CZ
      GO TO 45
40    Z2=CZ
C     WRITE (6,129) Z2
129   FORMAT(T10,' Z2    =',T17,F10.5)
C
C     CALCULATE AVERAGE GAS DENSITY
C
      AGDEN=SPGGAS*0.0764*(PAVG/14.7)*(520/(TAVG+460))*(1/AVGZ)
C     WRITE (6,130) AGDEN
130   FORMAT(T10,' AGDEN =',T17,F10.5)
```

```
C
C     CALCULATE AVERAGE VISCOSITY OF OIL
C
      S=3.0324-0.02023*(API)
      Y=10**(S)
      X=Y*(T1**(-1.163))
      ADOILV=(10**X)-1
      A=10.715*((RSAVG+100)**(-0.515))
      B=5.44*((RSAVG+150)**(-0.338))
      AOILV=(A*(ADOILV**B))
C     WRITE (6,131) AOILV
131   FORMAT(T10,'AOILV =',T17,F10.5)
C
C     CALCULATE AVERAGE WATER VISCOSITY
C
      AWTRV=EXP(1.003-1.479E-2*TAVG+1.982E-5*(TAVG**(-2)))
C     WRITE (6,132) AWTRV
132   FORMAT(T10,'AWTRV =',T17,F10.5)
C
C     CALCULATE LIQUID MIXTURE VISCOSITY
C
      ALIQV=AOILV*(1-WCUT)+AWTRV*(WCUT)
C     WRITE (6,133) ALIQV
133   FORMAT(T10,'ALIQV =',T17,F10.5)
C
C     CALCULATE LIQUID MIXTURE SURFACE TENSION
C
      STLIQM=STNOIL*(1-WCUT)+STNWTR*(WCUT)
C     WRITE (6,134) STLIQM
134   FORMAT(T10,'STLIQM=',T17,F10.5)
C
C     CALCULATE LIQUID VISCOSITY NUMBER
C
      VLN=0.15726*ALIQV*(1/(XLDEN*STLIQM**3))**0.25
C     WRITE (6,135) VLN
135   FORMAT(T10,'VLN   =',T17,F10.5)
C
C     CALCULATE VISCOSITY NUMBER CORRECTION FACTOR CNL
C
      A = 0.01001681
      B = -0.01522753
      C = -0.03911264
      D = -0.02739780
      E = -0.007981444
      F = -0.000842104
      CNLB = B*(ALOG10(VLN))
      CNLC = C*((ALOG10(VLN))**2)
      CNLD = D*((ALOG10(VLN))**3)
      CNLE = E*((ALOG10(VLN))**4)
      CNLF = F*((ALOG10(VLN))**5)
      CNL = A+CNLB+CNLC+CNLD+CNLE+CNLF
```

```
C     WRITE (6,136) CNL
136   FORMAT(T10,'CNL    =',T17,F10.5)
C
C     CALCULATE SUPERFICIAL LIQUID VELOCITY
C
      BW=1.0
      AVGVSL=5.61*((OILRTE+WTRRTE)/(86400*AREA))
     **(BOAVG*(1-WCUT)+BW*(WCUT))
C     WRITE (6,138) AVGVSL
138   FORMAT(T10,'AVGVSL=',T17,F10.5)
C     VSL1=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO1*(1-WCUT)+BW*(WCUT))
      A1=OILRTE+WTRRTE
      A2=86400*AREA
      A3=5.61*A1
      A4=A3/A2
      A5=1-WCUT
      A6=BO1*A5
      A7=BW*WCUT
      A8=A7+A6
      VSL1=A4*A8
C     WRITE (6,139) VSL1
139   FORMAT(T10,'VSL1   =',T17,F10.5)
C     VSL2=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO2*(1-WCUT)+BW*(WCUT))
      B1=OILRTE+WTRRTE
      B2=86400*AREA
      B3=5.61*B1
      B4=B3/B2
      B5=1-WCUT
      B6=BO1*B5
      B7=BW*WCUT
      B8=B7+B6
      VSL2=A4*A8
C     WRITE (6,140) VSL2
140   FORMAT(T10,'VSL2   =',T17,F10.5)
C
C     CALCULATE LIQUID VELOCITY NUMBER
C
      ANLV=1.938*AVGVSL*((XLDEN/STLIQM)**0.25)
C     WRITE (6,141) ANLV
141   FORMAT(T10,'ANLV   =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT PAVG AND TAVG
C
      AVSG=((OILRTE+WTRRTE)*(GLR-RSAVG*(1-WCUT))/(86400*AREA))*
     *(14.7/PAVG)*((TAVG+460)/520)*(AVGZ)
C     WRITE (6,142) AVSG
142   FORMAT(T10,'AVSG   =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P1 AND T1
C
C     VSG1=((OILRTE+WTRRTE)*(GLR-RS1*(1-WCUT))/(86400*AREA))*
```

```
C    *(14.7/P1)*((T1+460)/520)*(Z1)
      A1=OILRTE+WTRRTE
      A2=(1-WCUT)
      A3=RS1*A2
      A4=GLR-A3
      A5=86400*AREA
      A6=A4/A5
      A7=A1*A6
      B1=14.7/P1
      B2=T1+460
      B3=B2/520
      B4=B1*B3*Z1
      VSG1=A7*B4
C     WRITE (6,143) VSG1
143   FORMAT(T10,'VSG1  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P2 AND T2
C
      VSG2=((OILRTE+WTRRTE)*(GLR-RS2*(1-WCUT))/(86400*AREA))*
     *(14.7/P2)*((T2+460)/520)*(Z2)
C     WRITE (6,144) VSG2
144   FORMAT(T10,'VSG2  =',T17,F10.5)
C
C     CALCULATE GAS VELOCITY NUMBER
C
      ANGV=1.938*AVSG*((XLDEN/STLIQM)**0.25)
C     WRITE (6,145) ANGV
145   FORMAT(T10,'ANGV  =',T17,F10.5)
C     CALCULATE AA
      AA=1.071-(0.2218*((AVGVSL+AVSG)**2))/(DIAM)
C     WRITE (6,146) AA
146   FORMAT(T10,'AA    =',T17,F10.5)
      IF (AA.LT.0.13) AA=0.13
C     CALCULATE BB
      BB=AVSG/(AVGVSL+AVSG)
C     WRITE (6,147) BB
147   FORMAT(T10,'BB    =',T17,F10.5)
C     CALCULATE BB-AA
      CC=BB-AA
C ASSUME CC IS GE 1.0
CC    CC=1.0
C     WRITE (6,148) CC
148   FORMAT(T10,'CC    =',T17,F10.5)
      IF (CC.GE.0.0) GO TO 60
C
C
C     GRIFFITH CORRELATION FOR BUBBLE FLOW
C
C
C     CALCULATE LIQUID RATE & GAS RATE
C     GO TO 60
```

```
      VS=0.8
      QL=(6.49E-5)*((OILRTE*BOAVG)+(WTRRTE*BW))
C     WRITE (6,149) QL
149   FORMAT(T10,'QL     =',T17,F10.5)
CC    QG=(3.27E-7)*(AVGZ)*((OILRTE+WTRRTE)*(GLR-RSAVG)*(1-WCUT))*
CC   *((TAVG+460)/PAVG)
      QG=(3.27E-7)*(AVGZ)*((OILRTE)*(GOR-RSAVG))*
     *((TAVG+460)/PAVG)
C     WRITE (6,150) QG
150   FORMAT(T10,'QG     =',T17,F10.5)
      IF(QG.LE.0.0) GO TO 60
      QT=QL+QG
C     WRITE (6,151) QT
151   FORMAT(T10,'QT     =',T17,F10.5)
C
C     CALCULATE VOID FRACTION OF GAS
C
CC    HG=.5*(1+QT/(VS*AREA)-(((1+QT/(VS*AREA))**2-
CC   *4*QG/(VS*AREA))**.5))
CC    HG=.5*(1+QT/(AVSG*AREA)-(((1+QT/(AVSG*AREA))**2-
CC   *4*QG/(AVSG*AREA))**.5))
      XXA=(QT/(VS*AREA))
      XXB=(1+QT/(VS*AREA))**2
      XXC=((4*QG)/(VS*AREA))
      XXD=((XXB-XXC)**.5)
      XXE=1+XXA-XXD
      HG=0.5*XXE
C     WRITE (6,152) HG
152   FORMAT(T10,'HG     =',T17,F10.5)
C
C     CALCULATE AVERAGE FLOWING DENSITY
C
      AFD=(1-HG)*XLDEN+HG*AGDEN
C     WRITE (6,153) AFD
153   FORMAT(T10,'AFD    =',T17,F10.5)
C     CALCULATE LIQUID VELOCITY
      VL=QL/(AREA*(1-HG))
C     WRITE (6,154) VL
154   FORMAT(T10,'VL     =',T17,F10.5)
C
C     CALCULATE REYNOLDS NUMBER
C
      REN=1488*XLDEN*DIAM*VL/(ALIQV)
C     WRITE (6,155) REN
155   FORMAT(T10,'REN    =',T17,F20.10)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C     WRITE (6,156) RR
156   FORMAT(T10,'RR     =',T17,F10.5)
      IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 331
```

```
      IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 332
      IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 333
      IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 334
331   A1 = 0.26463610
      B1 = -0.11017749
      C1 = 0.01620292
      D1 = -0.000789492
      FF1B = B1*(ALOG10(REN))
      FF1C = C1*((ALOG10(REN))**2)
      FF1D = D1*((ALOG10(REN))**3)
      FF = A1+FF1B+FF1C+FF1D
      GO TO 337
332   A2 = 0.24272863
      B2 = -0.10086268
      C2 = 0.01497258
      D2 = -0.000735568
      FF2B = B2*(ALOG10(REN))
      FF2C = C2*((ALOG10(REN))**2)
      FF2D = D2*((ALOG10(REN))**3)
      FF = A2+FF2B+FF2C+FF2D
      GO TO 337
333   A3 = 0.23512834
      B3 = -0.09713003
      C3 = 0.01443852
      D3 = -0.000710073
      FF3B = B3*(ALOG10(REN))
      FF3C = C3*((ALOG10(REN))**2)
      FF3D = D3*((ALOG10(REN))**3)
      FF = A3+FF3B+FF3C+FF3D
      GO TO 337
334   A4 = 1.62171267
      B4 = -1.42794577
      C4 = 0.51701972
      D4 = -0.09404856
      E4 = 0.008523510
      F4 = -0.000306004
      FF4B = B4*(ALOG10(REN))
      FF4C = C4*((ALOG10(REN))**2)
      FF4D = D4*((ALOG10(REN))**3)
      FF4E = D4*((ALOG10(REN))**4)
      FF4F = D4*((ALOG10(REN))**5)
      FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
337   TAUF=FF*XLDEN*(VL**2)/(2*32.2*(DIAM))
      IF(REN.LE.2000) GO TO 16401
      GO TO 16402
16401 FF=64/REN
      GO TO 16405
16402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI
```

```
16406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16406
      FF=FGI
C37   WRITE (6,157) FF
157   FORMAT(T10,'FF    =',T17,F10.5)
C
C     CALCULATE TAU FRICTION
C
16405 TAUF=FF*XLDEN*(VL**2)/(2*32.2*(DIAM))
C     WRITE (6,158) TAUF
158   FORMAT(T10,'TAUF  =',T17,F10.5)
C
C     CALCULATE CORRECTED MASS FLOW RATE
C
      WL=4.05E-3*(OILRTE*SPGOIL+WTRRTE*SPGWTR)+8.85E-7*(OILRTE+WTRRTE)*
     *SPGGAS*(RSAVG)
C     WRITE (6,186) WL
186   FORMAT(T10,'WL    =',T17,F10.5)
C     CALCULATE CORRECTED FREE GAS FLOW RATE
C     WG=8.85E-7*(OILRTE+WTRRTE)*(GLR-RSAVG)
      WG=8.85E-7*(OILRTE)*(GOR-RSAVG)
C
C     CALCULATE TOTAL FLOW RATE
C
      WT=WL +WG
C     WRITE (6,185) WT
185   FORMAT(T10,'WT    =',T17,F10.5)
C
C     CALCULATE CHANGE IN DEPTH
C
C     DELTA1=144*(DELP)*(1-(WT*QG/(4637*(AREA**2)*(PAVG))))/(AFD+TAUF)
C     DDIF=ABS(DELTAH-DELTA1)
C     IF(DDIF.GT.0.25) GO TO 3001
C     GO TO 3002
C001  DELTAH=DELTA1
C     GO TO 1000
C002  DELTAH=DELTA1
C
```

```
C
C     WRITE (6,187) DELTAH
C87   FORMAT(T10,'DELTAH=',T17,F10.5)
      DELTAH=50
      XX1=AFD+TAUF
      XX2=4637*(AREA**2)*PAVG
      XX3=WT*QG
      XX4=XX3/XX2
      XX5=1-XX4
      XX6=XX5*144
      XX7=DELTAH*XX1
C     WRITE(6,884)XX6,XX7
C84   FORMAT(3X,2(F9.2,2X))
      YY=(XX7)/(XX6)
C     GO TO 60
C     WRITE (6,159) XY
C59   FORMAT(T10,'XY    =',T17,F20.10)
C     DDD2=ABS(DELP-DELPP)
C     IF(DDD2.GT.0.11) GO TO 1000
      ITER=ITER+1
      IF(ITER.GT.20) GO TO 900
      DIFF=ABS(DELP-YY)
      IF(DIFF.GT.1.00) GO TO 1000
C
C
C
      GO TO 900
C
C
C     CONTINUE WITH HAGEDORN AND BROWN CORRELATION
C
C
C     CALCULATE PIPE DIAMETER NUMBER
C
60    PND=((120.872*DIAM))*((XLDEN/STLIQM)**.5)
C     WRITE (6,160) PND
160   FORMAT(T10,'PND   =',T17,F10.5)
C
C     CALCULATE HOLDUP CORRELATING FUNCTION
C
      IF(ANGV.GT.0.0) GO TO 61
      HL=1.0
      GO TO 18
61    PHI=(ANLV/ANGV**0.575)*((PAVG/14.7)**0.1)*(CNL/PND)
C     WRITE (6,161) PHI
161   FORMAT(T10,'PHI   =',T17,F10.5)
C
C     CALCULATE HL/SI ( FIG. 2.34)
C
      IF (PHI.LE.3E-7) AHS=0.025
      IF (PHI.GT.3E-7.AND.PHI.LE.2.5E-6)
```

```
     *AHS=(ALOG10(PHI)-ALOG10(3E-7))*(3.49E-2)
      IF (PHI.GT.2.5E-6.AND.PHI.LE.5E-5)
     *AHS=(ALOG10(PHI)-ALOG10(2.5E-6))*(1.54E-1)+0.05
      IF (PHI.GT.5E-5.AND.PHI.LE.3E-4)
     *AHS=(ALOG10(PHI)-ALOG10(5E-5))*(3.86E-1)+0.25
      IF (PHI.GT.3E-4.AND.PHI.LE.1E-3)
     *AHS=(ALOG10(PHI)-ALOG10(3E-4))*(5.74E-1)+0.55
      IF (PHI.GT.1E-3.AND.PHI.LE.3E-3)
     *AHS=(ALOG10(PHI)-ALOG10(1E-3))*(2.1E-1)+0.85
      IF (PHI.GT.3E-3.AND.PHI.LE.1E-2)
     *AHS=(ALOG10(PHI)-ALOG10(3E-3))*(9.56E-2)+0.95
      IF (PHI.GT.1E-2) AHS=1.0
C     CALCULATE  PHI1
C     PHI2=ANGV*VLN**0.38/PND**2.14
      X1=VLN**0.38
      X2=ANGV*X1
      X3=PND**2.14
      PHI2=X2/X3
C     WRITE (6,162) PHI2
162   FORMAT(T10,'PHI2  =',T17,F10.5)
C
C     CALCULATE SI (FIG 2.57)
C
      IF (PHI2.LE.0.011) SI=1.0
      IF (PHI2.GT.0.011.AND.PHI2.LE.0.019) SI=1+8.75*(PHI2-0.011)
      IF (PHI2.GT.0.019.AND.PHI2.LE.0.024) SI=1.07+22.0*(PHI2-0.019)
      IF (PHI2.GT.0.024.AND.PHI2.LE.0.030) SI=1.18+36.7*(PHI2-0.024)
      IF (PHI2.GT.0.030.AND.PHI2.LE.0.035) SI=1.40+28.0*(PHI2-0.030)
      IF (PHI2.GT.0.035.AND.PHI2.LE.0.047) SI=1.54+10.8*(PHI2-0.035)
      IF (PHI2.GT.0.047.AND.PHI2.LE.0.063) SI=1.67+6.25*(PHI2-0.047)
      IF (PHI2.GT.0.063.AND.PHI2.LE.0.089) SI=1.77+1.92*(PHI2-0.063)
      IF (PHI2.GT.0.089) SI=1.82
C     WRITE (6,163) SI
163   FORMAT(T10,'SI    =',T17,F10.5)
C
C     CALCULATE HL: HOLD UP
C
      HL=AHS*SI
      IF (HL.GT.1.0) HL=1.0
C8    WRITE (6,164) HL
164   FORMAT(T10,'HL    =',T17,F10.5)
C
C     CALCULATE THE MOLECULAR WT OF THE GAS
C
18    GMWT=SPGGAS*29
C     WRITE (6,165) GMWT
165   FORMAT(T10,'GMWT  =',T17,F10.5)
C
C     CALCULATE VISCOSITY OF THE GAS
C
C     XXX=3.5+986/(TAVG+460)+0.01*GMWT
```

```
      C1=TAVG+460
      C2=986/C1
      C3=0.01*GMWT
      XXX=3.5+C2+C3
      GAMMA=2.4-0.2*XXX
C     AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
C    *(209+19*GMWT+(TAVG+460))
      D1=TAVG+460
      D2=D1**1.5
      D3=0.02*GMWT
      D4=D3+9.4
      D5=D4+D2
      D6=19*GMWT
      D7=209+D6
      D8=D7+D1
      AKKK=D5/D8
C     AGASVI=AKKK*0.0001*EXP(XXX*((AGDEN*454/30.8**3)**GAMMA))
      E1=AGDEN*454
      E2=30.28**3
      E3=E1/E2
      E4=E3**GAMMA
      E5=E4*XXX
      E6=EXP(E5)
      AGASVI=AKKK*0.0001*E6

C     WRITE (6,166) AGASVI
166   FORMAT(T10,'AGASVI=',T17,F10.5)
C
C     CALCULATE TWO PHASE REYNOLD NUMBER
C
C     TPREN=0.022*W1/(DIAM*(ALIQV**HL)*(AGASVI**(1-HL)))
      G1=ALIQV**HL
      G2=DIAM*G1
      G3=1-HL
      G4=AGASVI**G3
      G5=G2*G4
      G6=0.022*W1
      TPREN=G6/G5
      REN=TPREN
C     WRITE (6,167) TPREN
167   FORMAT(T10,'TPREN =',T17,F20.10)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
      IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 431
      IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 432
      IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 433
      IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 434
431   A1 = 0.26463610
      B1 = -0.11017749
      C1 = 0.01620292
```

```
      D1 = -0.000789492
      FF1B = B1*(ALOG10(TPREN))
      FF1C = C1*((ALOG10(TPREN))**2)
      FF1D = D1*((ALOG10(TPREN))**3)
      FF = A1+FF1B+FF1C+FF1D
      GO TO 437
432   A2 = 0.24272863
      B2 = -0.10086268
      C2 = 0.01497258
      D2 = -0.000735568
      FF2B = B2*(ALOG10(TPREN))
      FF2C = C2*((ALOG10(TPREN))**2)
      FF2D = D2*((ALOG10(TPREN))**3)
      FF = A2+FF2B+FF2C+FF2D
      GO TO 437
433   A3 = 0.23512834
      B3 = -0.09713003
      C3 = 0.01443852
      D3 = -0.000710073
      FF3B = B3*(ALOG10(TPREN))
      FF3C = C3*((ALOG10(TPREN))**2)
      FF3D = D3*((ALOG10(TPREN))**3)
      FF = A3+FF3B+FF3C+FF3D
      GO TO 437
434   A4 = 1.62171267
      B4 = -1.42794577
      C4 = 0.51701972
      D4 = -0.09404856
      E4 = 0.008523510
      F4 = -0.000306004
      FF4B = B4*(ALOG10(REN))
      FF4C = C4*((ALOG10(TPREN))**2)
      FF4D = D4*((ALOG10(TPREN))**3)
      FF4E = D4*((ALOG10(TPREN))**4)
      FF4F = D4*((ALOG10(TPREN))**5)
      FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
437   AMDEN1=XLDEN*HL+AGDEN*(1-HL)
      IF(REN.LE.2000) GO TO 17401
      GO TO 17402
17401 FF=64/REN
      GO TO 17405
17402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

17406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
```

```
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 17405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 17406
      FF=FGI
C     WRITE (6,168) FF
168   FORMAT(T10,'FF    =',T17,F20.10)
C
C     CALCULATE MIXTURE DENSITY
C
C     FIRST METHOD
C
17405 AMDEN1=XLDEN*HL+AGDEN*(1-HL)
C     WRITE (6,169) AMDEN1
169   FORMAT(T10,'AMDEN1=',T17,F20.10)
C
C     SECOND METHOD
C
C     CALCULATE GOR
C
      GOR=(OILRTE+WTRRTE)*GLR/OILRTE
C     WRITE (6,170) GOR
170   FORMAT(T10,'GOR   =',T17,F20.10)
C     CAL. MASS OF OIL, GAS AND WATER ASSOCIATED WITH ONE BBL OF OIL
      CM2=350*SPGOIL+0.0764*SPGGAS*GOR+350*SPGWTR*WOR
C     WRITE (6,171) CM2
171   FORMAT(T10,'CM2   =',T17,F20.10)
C
C     CALCULATE TOTAL MASS OF PRODUCED FLUID PER DAY
C
      W2=CM2*OILRTE
C     WRITE (6,172) W2
172   FORMAT(T10,'W2    =',T17,F20.10)
C
C     CAL. VOLUME OF MIXTURE OF OIL WATER AND GAS
C
      AVM2=5.61*BOAVG+5.61*WOR+(GOR-RSAVG)*(14.7/PAVG)*((TAVG+460)
     */520)*AVGZ
C     WRITE (6,173) AVM2
173   FORMAT(T10,'AVM2  =',T17,F20.10)
C
C     CALCULATE MIXTURE DENSITY
C

      AMDEN2=CM2/AVM2
C     WRITE (6,174) AMDEN2
```

```
174   FORMAT(T10,'AMDEN2=',T17,F20.10)
C
C     CHECK WHICH CALCULATED DENSITY IS GREATER AND USE
C
      IF(AMDEN1.GE.AMDEN2) GO TO 200
      AMDEN=AMDEN2
      GO TO 210
200   AMDEN=AMDEN1
C10   WRITE (6,175) AMDEN
175   FORMAT(T10,'AMDEN =',T17,F20.10)
C
C     CALCULAT MIXTURE VELOCITIES AT 1 AND 2
C
210   VM1=VSL1+VSG1
C     WRITE (6,176) VM1
176   FORMAT(T10,'VM1   =',T17,F20.10)
      VM2=VSL2+VSG2
C     WRITE (6,177) VM2
177   FORMAT(T10,'VM2   =',T17,F20.10)
C     CALCULATE DELTA H
C
C     DELTAH=(144*DELP-AMDEN*((VM1**2)-(VM2**2))/(2*32.2))/
C    *(AMDEN+(FF*(W1**2))/(2.9652E11*((DIAM)**5)*AMDEN))
C
      XX1=VM1**2
      XX2=VM2**2
      XX3=XX1-XX2
      XX4=AMDEN*XX3
      XX5=XX4/2
      XX6=XX5/32.2
C
      XX7=W1**2
      XX8=FF*XX7
      XX9=XX8/2.9652E11
      YY1=XX9/(DIAM**5)
      YY2=YY1/AMDEN
      YY3=AMDEN+YY2
      YY4=YY3*DELTAH
      YY5=YY4+XX6
      DELPP=YY5/144
C
      DDD2=ABS(DELP-DELPP)
      IF(DDD2.GT.0.11) GO TO 1000
C
C
C
C
C
C     X1=VM1**2
C     X2=VM2**2
C     X3=X1-X2
```

```
C     X4=AMDEN*X3
C     X4=X4/2
C     X4=X4/32.2
C     X5=144*DELP
C     X6=X5-X4
C     Y1=W1**2
C     Y2=FF*Y1
C     Y3=2.9652E11
C     Y4=DIAM
C     Y5=Y4**5
C     Y6=Y3*Y5
C     Y7=Y6*AMDEN
C     Y8=Y2/Y7
C     Y9=AMDEN+Y8
C     DELTAH=X6/Y9
C     CALCULATE TOTAL DEPTH
900   DEPTH1=DEPTH1+DELTAH
      IF(DEPTH1.GE.TOTDEP) GO TO 1831
      GO TO 1832
1831  DEPTH2=DEPTH1-TOTDEP
      DDD1=DEPTH2/DELTAH
      DDD2=DDD1*DELP
      P2=P2-DDD2
      DEPTH1=DEPTH1-DEPTH2
C
1832  IF(IPROF.EQ.1) WRITE(11,184)DEPTH1,P2
184   FORMAT(3X,2(F9.2,2X))
C
      FGE=DEPTH1-TOTDEP
      IF(FGE.EQ.0.0) GO TO 250
C
C     CHECK IF TOTAL DEPTH IS REACHED
C
C     ASSUME P1 EQUAL TO P2 AND DEPTH1 EQUAL TO DEPTH2 AND ITERATE
C
      P1=P2
      T1=T2
C     DEPTH1=CDEPTH
      GO TO 11
250   BHFP=P2
      RETURN
      END
```

```
C
C     THIS IS THE ORIGINAL DUN PROGRAM
C
C     DUN
      SUBROUTINE DUN(VS,RESTMP,SURTMP,P1,DEPTH1,OILRTE,WTRRTE,DIMTB,
     &API,GOR,DIMTSG,DIMTBG,SPGWTR,SPGGAS,STNOIL,STNWTR,BW,EE,
     &DELP,DELTAH,G,GC,T1,TOTDEP,DIMTB2,DEPTB2,BHFP,IPROF)
C
C     STEP : 1 CALCULATE SPECIFIC GRAVITY OF OIL
      SPGOIL=141.5/(131.5+API)
C     WRITE (6,101) SPGOIL
101   FORMAT(T10,' SPGOIL =',T17,F10.5)
C     STEP : 2 CALCULATE GLR WOR WCUT TOTAL LIQUID AND FLUID GRADIENT
      GLR=GOR*(OILRTE/(OILRTE+WTRRTE))
C     WRITE (8,102) GLR
C02   FORMAT(T10,' GLR =',T17,F10.5)
      WOR=WTRRTE/OILRTE
C     WRITE (8,103) WOR
C03   FORMAT(T10,' WOR =',T17,F10.5)
      WCUT=WTRRTE/(OILRTE+WTRRTE)
C     WRITE (6,104) WCUT
104   FORMAT(T10,' WCUT =',T17,F10.5)
      DEPTH1=0
      TOTLIQ=OILRTE+WTRRTE
C     WRITE (8,105) TOTLIQ
C05   FORMAT(T10,' TOTLIQ =',T17,F10.1)
      APRXGD=.433*WCUT+SPGOIL*.433*(1.0-WCUT)
C     WRITE (8,106) APRXGD
C06   FORMAT(T10,' APRXGD =',T17,F10.5)
C     WRITE (8,107) DIAM
C07   FORMAT(T10,' DIAM =',T17,F10.5)
C     STEP : 4 CALCULATE MASS ASSOCIATED WITH 1 STB OF LIQUID
      AMASS=((SPGOIL*350.0)*(1.0-WCUT))
      BMASS=SPGWTR*350.0*WCUT
      CMASS=0.0764*GOR*SPGGAS
      TM=AMASS+BMASS+CMASS
C     WRITE (8,108) TM
C08   FORMAT(T10,' TM   =',T17,F10.5)
C     STEP : 5 CALCULATE MASS FLOW RATE
      W1=TM*TOTLIQ
C     WRITE (8,109) W1
C09   FORMAT(T10,' W1   =',T17,F10.0)
C     STEP : 6 CALCULATE TEMPERATURE GRADIENT
      TEMGRD=(RESTMP-SURTMP)/TOTDEP
C     WRITE (8,110) TEMGRD
C10   FORMAT(T10,' TEMGRD=',T17,F10.5)
C     WRITE (8,111) T1
C11   FORMAT(T10,' T1    =',T17,F10.5)
C     STEP : 7 CALCULATE AVERAGE TEMP AND AVERAGE PRESS
C11   DELDEP=DELP/APRXGD
      DELP=DELTAH*APRXGD
```

```
11     DELP=25
       GO TO 23766
23765 DELP=DELPX
C      STEP : 3 CALCULATE HYDRAULIC DIAMETER
C               DIMTSG: INSIDE DIAMETER OF THE CASING
C               DIMTBG: OUTSIDE DIAMETER OF THE TUBING
C               DIMTB : INSIDE DIAMETER OF THE TUBING
C      CALCULATE THE AREA OF FLOW
23766 IF(DIMTSG.EQ.0.0) GO TO 12
       AREA=(22/7)*((DIMTSG**2-DIMTBG**2)/4)
       GO TO 14
12     IF(DEPTH1.LE.DEPTB2) GO TO 938
       DIAM=DIMTB2
       GO TO 14001
938    DIAM=DIMTB
14001 AREA=22*(DIAM**2)/(4*7)
14     CONTINUE
C      WRITE (8,112) DELDEP
C12    FORMAT(T10,' DELDEP=',T17,F10.5)
       T2=T1+TEMGRD*DELTAH
C      WRITE (8,113) T2
C13    FORMAT(T10,' T2    =',T17,F10.5)
       TAVG=(T1+T2)/2
C      WRITE (8,114) TAVG
C14    FORMAT(T10,' TAVG  =',T17,F10.5)
       P2=P1+DELP
C      WRITE (8,115) P2
C15    FORMAT(T10,' P2    =',T17,F10.5)
C      WRITE (8,116) P1
C16    FORMAT(T10,' P1    =',T17,F10.5)
       PAVG=(P1+P2)/2+14.7
C      PAVG=(P1+P2)/2
C      WRITE (8,117) PAVG
C17    FORMAT(T10,' PAVG  =',T17,F10.5)
C      STEP : 8 CALCULATE SOLUTION GAS AT AVGP P1 P2
19     XC1=PAVG/18
       XC2=(10**((.0125*(API))))
       XC3=(10**(0.00091*(TAVG)))
       XC4=((XC1*(XC2/XC3)))
       IF(XC4.LT.0.0) XC4=0.0
       XC4=(XC4)**(1/0.83)
       RSAVG=SPGGAS*XC4
       IF(RSAVG.LE.GOR) GO TO 1111
       RSAVG=GOR
C111   WRITE (6,118) RSAVG
118    FORMAT(T10,' RSAVG =',T17,F10.5)
C      P1
C111   X5=P1/18
C      X6=(10**((.0125*(API))-(0.00091*T1)))
C      X7=(((X5*X6))**(1/0.83))
C      RS1=SPGGAS*X7
```

```
C     IF(RS1.LE.GOR) GO TO 20
C     RS1=GOR
C0    WRITE (8,119) RS1
C19   FORMAT(T10,' RS1    =',T17,F10.5)
C     P2
C0    X9=P2/18
C     X10=(10**((.0125*(API))-(0.00091*T2)))
C     X11=(((X9*X10))**(1/0.83))
C     RS2=SPGGAS*X11
C     IF(RS2.LE.GOR) GO TO 21
C     RS2=GOR
C1    WRITE (8,120) RS2
C20   FORMAT(T10,' RS2    =',T17,F10.5)
C     CONTINUE
C     STEP : 9 CALCULATE FORM. VOL. FACTOR AT PAVG,TAVG P1,T1 P2,T2
1111  FAVG=((RSAVG*((SPGGAS/SPGOIL)**0.5))+(1.25*TAVG))
C     WRITE(8,990)FAVG
C90   FORMAT(3X,(F8.2,3X))
      BOAVG=(0.972+((0.000147)*((FAVG**1.175))))
C     WRITE (6,121) BOAVG
C21   FORMAT(T10,' BOAVG =',T17,F10.5)
C     F1=((RS1*((SPGGAS/SPGOIL)**0.5))+(1.25*T1))
C     BO1=(0.972+((0.000147)*((F1**1.175))))
C     WRITE (8,122) BO1
C22   FORMAT(T10,' BO1    =',T17,F10.5)
C     F2=((RS2*((SPGGAS/SPGOIL)**0.5))+(1.25*T2))
C     BO2=(0.972+((0.000147)*((F2**1.175))))
C     WRITE (8,123) BO2
C23   FORMAT(T10,' BO2    =',T17,F10.5)
C     STEP : 10 CALCULATE THE DENSITY OF THE LIQUID PHASE
C     G1=(SPGOIL*(62.4)+(RSAVG*SPGGAS*(0.0764))/(5.614))
C     G2=((G1/BOAVG)*(1-WCUT))
C     G3=((SPGWTR)*(62.4)*(WCUT))
C     XLDEN=(G2+G3)
      XZ1=SPGOIL*62.4
      XZ2=RSAVG*SPGGAS*(0.0764)
      XZ2=XZ2/5.614
      XZ3=XZ1+XZ2
      XZ4=XZ3/BOAVG
      XZ4=XZ4*(1-WCUT)
      XZ5=SPGWTR*62.4*WCUT
      XLDEN=XZ4+XZ5
C     WRITE (6,124) XLDEN
124   FORMAT(T10,'XLDEN  =',T17,F10.5)
C     AT P1
C     G4=(SPGOIL*(62.4)+(RS1*SPGGAS*(0.0764))/(5.614))
C     G5=((G4/BO1)*(1-WCUT))
C     G6=((SPGWTR)*(62.4)*(WCUT))
C     DEN1=(G5+G6)
C     WRITE (8,125) DEN1
C25   FORMAT(T10,' DEN1   =',T17,F10.5)
```

```
C       AT P2
C       G7=(SPGOIL*(62.4)+(RS2*SPGGAS*(0.0764))/(5.614))
C       G8=((G7/BO2)*(1-WCUT))
C       G9=((SPGWTR)*(62.4)*(WCUT))
C       DEN2=(G8+G9)
C       WRITE (8,126) DEN2
C26     FORMAT(T10,' DEN2  =',T17,F10.5)
C       CALCULATE COMPRESSIBILITY FACTOR AT PAVG,TAVG P1,T1 P2,T2
        PPC=(709.604-58.718*(SPGGAS))
        TPC=(170.491+307.344*(SPGGAS))
        APR=PAVG/PPC
        ATR=(TAVG+460)/TPC
        PR1=(P1+14.7)/PPC
        TR1=(T1+460)/TPC
        PR2=(P2+14.7)/PPC
        TR2=(T2+460)/TPC
C       COEFFICIENTS
        A1=0.31506237
        A2=-1.04670990
        A3=-0.57832729
        A4=0.53530771
        A5=-0.61232032
        A6=-0.10488813
        A7=0.68157001
        A8=0.68446549
C       AT PAVG TAVG  ASSUME Z=1.0
        PR=APR
        TR=ATR
        AZ=1.0
15      CPR=(0.27*PR)/(AZ*TR)
        AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
        AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
        AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
        CZ=AK1+(AK2*AK3)
        ZDIF=ABS(CZ-AZ)
        IF(ZDIF.LE.0.0001)  GO TO 30
        AZ=CZ
        GO TO 15
30      AVGZ=CZ
C       WRITE (8,127) AVGZ
C27     FORMAT(T10,' AVGZ  =',T17,F10.5)
C       AT P1 T1
        PR=PR1
        TR=TR1
        AZ=1.0
25      CPR=(0.27*PR)/(AZ*TR)
        AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
        AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
        AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
        CZ=AK1+(AK2*AK3)
        ZDIF=ABS(CZ-AZ)
```

```
      IF(ZDIF.LE.0.0001)  GO TO 35
      AZ=CZ
      GO TO 25
35    Z1=CZ
C     WRITE (8,128) Z1
C28   FORMAT(T10,' Z1    =',T17,F10.5)
C     AT P2 T2
      PR=PR2
      TR=TR2
      AZ=1.0
45    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 40
      AZ=CZ
      GO TO 45
40    Z2=CZ
C     WRITE (8,129) Z2
C29   FORMAT(T10,' Z2    =',T17,F10.5)
C     CALCULATE AVERAGE GAS DENSITY
      AGDEN=SPGGAS*0.0764*(PAVG/14.7)*(520/(TAVG+460))*(1/AVGZ)
      IF(AGDEN.LT.0.0) AGDEN=0.0
C     WRITE (8,130) AGDEN
C30   FORMAT(T10,' AGDEN =',T17,F10.5)
C     CALCULATE AVERAGE VISCOSITY OF OIL
      S=3.0324-0.02023*(API)
      Y=10**(S)
      X=Y*(T1**(-1.163))
      ADOILV=(10**X)-1
      A=10.715*((RSAVG+100)**(-0.515))
      B=5.44*((RSAVG+150)**(-0.338))
      AOILV=(A*(ADOILV**B))
C     WRITE (6,131) AOILV
131   FORMAT(T10,'AOILV =',T17,F10.5)
C     CALCULATE AVERAGE WATER VISCOSITY
      AWTRV=EXP(1.003-1.479E-2*TAVG+1.982E-5*(TAVG**(-2)))
C     WRITE (8,132) AWTRV
C32   FORMAT(T10,'AWTRV =',T17,F10.5)
C     CALCULATE LIQUID MIXTURE VISCOSITY
      ALIQV=AOILV*(1-WCUT)+AWTRV*(WCUT)
C     WRITE (8,133) ALIQV
C33   FORMAT(T10,'ALIQV =',T17,F10.5)
C     CALCULATE LIQUID MIXTURE SURFACE TENSION
C
C
      STLIQM=STNOIL*(1-WCUT)+STNWTR*(WCUT)
C     WRITE (6,134) STLIQM
134   FORMAT(T10,'STLIQM=',T17,F10.5)
```

```
C     CALCULATE LIQUID VISCOSITY NUMBER
      VLN=0.15726*ALIQV*((1/(XLDEN*(STLIQM**3)))**0.25)
C     WRITE (8,135) VLN
C35   FORMAT(T10,'VLN   =',T17,F10.5)
C     CALCULATE VISCOSITY NUMBER CORRECTION FACTOR CNL
      A = 0.01001681
      B = -0.01522753
      C = -0.03911264
      D = -0.02739780
      E = -0.007981444
      F = -0.000842104
      CNLB = B*(ALOG10(VLN))
      CNLC = C*((ALOG10(VLN))**2)
      CNLD = D*((ALOG10(VLN))**3)
      CNLE = E*((ALOG10(VLN))**4)
      CNLF = F*((ALOG10(VLN))**5)
      CNL = A+CNLB+CNLC+CNLD+CNLE+CNLF
C     WRITE (8,136) CNL
C36   FORMAT(T10,'CNL   =',T17,F10.5)
C     CALCULATE SUPERFICIAL LIQUID VELOCITY
      BW=1.0
      VSL=5.61*((OILRTE+WTRRTE)/(86400*AREA))
     **(BOAVG*(1-WCUT)+BW*(WCUT))
      IF(VSL.LT.0.1) GO TO 45001
      GO TO 45002
45001 VSL=0.1
C     WRITE (6,138) VSL
138   FORMAT(T10,'VSL=',T17,F10.5)
C5002 VSL1=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO1*(1-WCUT)+BW*(WCUT))
C     WRITE (8,139) VSL1
C39   FORMAT(T10,'VSL1  =',T17,F10.5)
C     VSL2=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO2*(1-WCUT)+BW*(WCUT))
C     WRITE (8,140) VSL2
C40   FORMAT(T10,'VSL2  =',T17,F10.5)
C     CALCULATE LIQUID VELOCITY NUMBER
45002 ANLV=1.938*VSL*((XLDEN/STLIQM)**0.25)
C     WRITE (6,141) ANLV
141   FORMAT(T10,'ANLV  =',T17,F10.5)
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT PAVG AND TAVG
C     VSG=((OILRTE+WTRRTE)*(GLR-RSAVG*(1-WCUT))/(86400*AREA))*
      VSG=((OILRTE)*(GOR-RSAVG)/(86400*AREA))*
     *(14.7/(PAVG))*((TAVG+460)/520)*(AVGZ)
      IF(VSG.LT.0.0) GO TO 6666
      GO TO 6667
6666  VSG=0.0
C667  WRITE (6,142) VSG
142   FORMAT(T10,'VSG  =',T17,F10.5)
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P1 AND T1
C667  VSG1=((OILRTE+WTRRTE)*(GLR-RS1*(1-WCUT))/(86400*AREA))*
C    *(14.7/P1)*((T1+460)/520)*(Z1)
C     WRITE (8,143) VSG1
```

```
C43   FORMAT(T10,'VSG1  =',T17,F10.5)
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P2 AND T2
C     VSG2=((OILRTE+WTRRTE)*(GLR-RS2*(1-WCUT))/(86400*AREA))*
C    *(14.7/P2)*((T2+460)/520)*(Z2)
C     WRITE (8,144) VSG2
C44   FORMAT(T10,'VSG2  =',T17,F10.5)
C     CALCULATE GAS VELOCITY NUMBER
6667  ANGV=1.938*VSG*((XLDEN/STLIQM)**0.25)
      IF(ANGV.GT.85) GO TO 800
C     WRITE (6,145) ANGV
145   FORMAT(T10,'ANGV  =',T17,F10.5)
C     ************************************************************
C             ****************************************
C     ************************************************************
C     CALCULATE PIPE DIAMETER NUMBER
      AND=120.872*(DIAM)*((XLDEN/STLIQM)**0.5)
C     WRITE (6,146) AND
146   FORMAT(T10,'AND    =',T17,F10.5)
C     *******************************************************
C     PUT F1 F2 F3 F4 F5 F6 F7 VS VLN
C     PUT L1 L2 VS AND
C     *******************************************************
C     *******************************************************
C                                F1
C     *******************************************************
      IF(VLN.LT.0.004333)  GO TO 9806
      IF(VLN.GT.1.9074)   GO TO 9807
      A9=1.19870635
      B9=-1.63992697
      C9=0.36955752
      D9=2.81315804
      E9=5.96769347
      F9=9.20047888
      G9=6.96177741
      H9=2.40652979
      S9=0.30971857
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      FFE9=E9*((ALOG10(VLN))**4)
      FFF9=F9*((ALOG10(VLN))**5)
      FFG9=G9*((ALOG10(VLN))**6)
      FFH9=H9*((ALOG10(VLN))**7)
      FFS9=S9*((ALOG10(VLN))**8)
      F1=A9+FFB9+FFC9+FFD9+FFE9+FFF9+FFG9+FFH9+FFS9
      GO TO 9808
9806  F1=1.3119
      GO TO 9808
9807  F1=0.8800
C808  WRITE (8,147) F1
C47   FORMAT(T10,'F1     =',T17,F10.5)
```

```
C     ************************************************************
C                                F2
C     ************************************************************
9808  IF(VLN.LT.0.002000)   GO TO 9809
      IF(VLN.GT.1.833000)   GO TO 9810
      A9=0.81324125
      B9=-0.15245312
      C9=0.10843548
      D9=-2.60776333
      E9=-5.99537408
      F9=-4.41730852
      G9=-1.35692764
      H9=-0.15046044
      S9=0.0
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      FFE9=E9*((ALOG10(VLN))**4)
      FFF9=F9*((ALOG10(VLN))**5)
      FFG9=G9*((ALOG10(VLN))**6)
      FFH9=H9*((ALOG10(VLN))**7)
      FFS9=S9*((ALOG10(VLN))**8)
      F2=A9+FFB9+FFC9+FFD9+FFE9+FFF9+FFG9+FFH9+FFS9
      GO TO 9811
9809  F2=0.24688
      GO TO 9811
9810  F2=0.7000
C811  WRITE (8,148) F2
C48   FORMAT(T10,'F2     =',T17,F10.5)
C     ************************************************************
C                                F3
C     ************************************************************
9811  IF(VLN.LT.0.002000)   GO TO 9812
      IF(VLN.GT.2.000000)   GO TO 9813
      A9=3.75224830
      B9=-0.07886940
      C9=0.81760118
      D9=4.18987189
      E9=5.18601484
      F9=3.32537947
      G9=1.04924104
      H9=0.12577796
      S9=0.0
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      FFE9=E9*((ALOG10(VLN))**4)
      FFF9=F9*((ALOG10(VLN))**5)
      FFG9=G9*((ALOG10(VLN))**6)
      FFH9=H9*((ALOG10(VLN))**7)
      FFS9=S9*((ALOG10(VLN))**8)
```

```
      F3=A9+FFB9+FFC9+FFD9+FFE9+FFF9+FFG9+FFH9+FFS9
      GO TO 9814
9812  F3=0.8316
      GO TO 9814
9813  F3=3.9684
C814  WRITE (8,149) F3
C49   FORMAT(T10,'F3     =',T17,F10.5)
C     ************************************************************
C                                F4
C     ************************************************************
9814  IF(VLN.LT.0.002000)   GO TO 9815
      IF(VLN.GT.1.840000)   GO TO 9816
      A9=77.36032248
      B9=13.19940518
      C9=-189.81881
      D9=-468.44300
      E9=-459.03931
      F9=-217.72022
      G9=-50.29549857
      H9=-4.53322015
      S9=0.0
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      FFE9=E9*((ALOG10(VLN))**4)
      FFF9=F9*((ALOG10(VLN))**5)
      FFG9=G9*((ALOG10(VLN))**6)
      FFH9=H9*((ALOG10(VLN))**7)
      FFS9=S9*((ALOG10(VLN))**8)
      F4=A9+FFB9+FFC9+FFD9+FFE9+FFF9+FFG9+FFH9+FFS9
      GO TO 9817
9815  F4=-20.000
      GO TO 9817
9816  F4=56.2857
C817  WRITE (8,150) F4
C50   FORMAT(T10,'F4     =',T17,F10.5)
C     ************************************************************
C                                F5
C     ************************************************************
9817  IF(VLN.LT.0.001860)   GO TO 9818
      IF(VLN.GT.2.000000)   GO TO 9819
      A9=0.08841614
      B9=0.07876697
      C9=0.17924594
      D9=0.28193052
      E9=-1.12054959
      F9=-3.42008808
      G9=-3.36897560
      H9=-1.49825744
      S9=-0.27376640
      X9=0.0
```

```
      Y9=0.004107449
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      FFE9=E9*((ALOG10(VLN))**4)
      FFF9=F9*((ALOG10(VLN))**5)
      FFG9=G9*((ALOG10(VLN))**6)
      FFH9=H9*((ALOG10(VLN))**7)
      FFS9=S9*((ALOG10(VLN))**8)
      FFX9=X9*((ALOG10(VLN))**9)
      FFY9=Y9*((ALOG10(VLN))**10)
      F5=A9+FFB9+FFC9+FFD9+FFE9+FFF9+FFG9+FFH9+FFS9+FFX9+FFY9
      GO TO 9820
9818  F5=0.23125
      GO TO 9820
9819  F5=0.11591
C820  WRITE (8,151) F5
C51   FORMAT(T10,'F5     =',T17,F10.5)
C     ***********************************************************
C                                F6
C     ***********************************************************
9820  IF(VLN.LT.0.002000)   GO TO 9821
      IF(VLN.GT.2.000000)   GO TO 9822
      A9=1.74689394
      B9=-0.26902124
      C9=-1.53550036
      D9=2.11403988
      E9=18.71228439
      F9=15.77799219
      G9=-14.23906754
      H9=-23.93600826
      S9=-9.57820668
      X9=0.0
      Y9=0.63414991
      V9=0.0
      W9=-0.03167866
      Z9=0.0
      O9=0.0
      Q9=-0.000185900
      P9=0.0
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      FFE9=E9*((ALOG10(VLN))**4)
      FFF9=F9*((ALOG10(VLN))**5)
      FFG9=G9*((ALOG10(VLN))**6)
      FFH9=H9*((ALOG10(VLN))**7)
      FFS9=S9*((ALOG10(VLN))**8)
      FFX9=X9*((ALOG10(VLN))**9)
      FFY9=Y9*((ALOG10(VLN))**10)
      FFV9=V9*((ALOG10(VLN))**11)
```

```
      FFW9=W9*((ALOG10(VLN))**12)
      FFZ9=Z9*((ALOG10(VLN))**13)
      FFO9=O9*((ALOG10(VLN))**14)
      FFQ9=Q9*((ALOG10(VLN))**15)
      FFP9=P9*((ALOG10(VLN))**16)
      F6=A9+FFB9+FFC9+FFD9+FFE9+FFF9+FFG9+FFH9+FFS9+FFX9+FFY9+
     *FFV9+FFW9+FFZ9+FFO9+FFQ9+FFP9
      GO TO 9823
9821  F6=0.85333
      GO TO 9823
9822  F6=1.76000
C823  WRITE (8,152) F6
C52   FORMAT(T10,'F6     =',T17,F10.5)
C     **************************************************************
C                                F7
C     **************************************************************
9823  IF(VLN.LT.0.0022295)   GO TO 9824
      IF(VLN.GT.3.000000)   GO TO 9825
      A9=0.02454313
      B9=-0.004630091
      C9=0.01024156
      D9=-0.001797399
      FFB9=B9*(ALOG10(VLN))
      FFC9=C9*((ALOG10(VLN))**2)
      FFD9=D9*((ALOG10(VLN))**3)
      F7=A9+FFB9+FFC9+FFD9
      GO TO 9826
9824  F7=0.1407
      GO TO 9826
9825  F7=0.02396
C     WRITE (8,153) F7
C53   FORMAT(T10,'F7     =',T17,F10.5)
CC
C     **************************************************************
C                                L1
C     **************************************************************
9826  IF(AND.LT.10) GO TO 9800
      IF(AND.GT.300) GO TO 9801
      A9=-4.23311929
      B9=12.87302803
      C9=-7.64429294
      D9=0.77704702
      E9=0.22352108
      F9=0.0
      FFB9=B9*(ALOG10(AND))
      FFC9=C9*((ALOG10(AND))**2)
      FFD9=D9*((ALOG10(AND))**3)
      FFE9=E9*((ALOG10(AND))**4)
      FFF9=F9*((ALOG10(AND))**5)
      AL1=A9+FFB9+FFC9+FFD9+FFE9+FFF9
      GO TO 9802
```

```
9800  AL1=2.0
      GO TO 9802
9801  AL1=0.975
C802  WRITE (8,154) AL1
C54   FORMAT(T10,'AL1    =',T17,F20.9)
C     ***********************************************************
C                                    L2
C     ***********************************************************
9802  IF(AND.LT.14.7) GO TO 9803
      IF(AND.GT.300) GO TO 9804
      A9=21.76361711
      B9=-53.22658322
      C9=47.63716663
      D9=-18.03094649
      E9=2.46809618
      F9=0.0
      FFB9=B9*(ALOG10(AND))
      FFC9=C9*((ALOG10(AND))**2)
      FFD9=D9*((ALOG10(AND))**3)
      FFE9=E9*((ALOG10(AND))**4)
      FFF9=F9*((ALOG10(AND))**5)
      AL2=A9+FFB9+FFC9+FFD9+FFE9+FFF9
      GO TO 9805
9803  AL2=0.4450
      GO TO 9805
9804  AL2=1.0825
C805  WRITE (8,155) AL2
C55   FORMAT(T10,'AL2    =',T17,F20.9)
C     ***********************************************************
9805  Y1=AL1+AL2*ANLV
C     WRITE (8,156) Y1
C56   FORMAT(T10,'Y1     =',T17,F20.9)
C     IF(ANGV.GE.0.0.AND.ANGV.LE.Y1) GO TO 500
      Y2=50+36*ANLV
C     WRITE (8,157) Y2
C57   FORMAT(T10,'Y2     =',T17,F20.9)
C     IF(ANGV.GT.Y1.AND.ANGV.LT.Y2) GO TO 600
      Y3=75+(84*(ANLV**0.75))
C     WRITE (8,158) Y3
C58   FORMAT(T10,'Y3     =',T17,F20.9)
C     IF(ANGV.GT.Y3) GO TO 800
C     GO TO 700

C
C
C     WEISMAN AND KING FLOW PATTERN
C
C
C
C     FOR BUBBLE TO INTERMITTENT
C
```

```
C
C
C     X1=VSG**2
C     X2=G*DIAM
C     FRG=X1/X2
C
C     X3=VSG+VSL
C     X4=G*DIAM
C     X5=X4**(0.5)
C     FRT=X3/X5
C     X6=FRT**(1.56)
C     X7=0.2*X6
C
C
C     FOR INTERMITTENT TO ANNULAR
C
C
C
C     Y1=VSG/VSL
C     Y2=Y1**(5./8.)
C     Y3=25*Y2
C
C     Y4=VSG**2
C     Y5=G*DIAM
C     FRG=Y4/Y5
C
C     Y6=AGDEN**(0.5)
C     Y7=Y6*VSG
C     Y8=(XLDEN-AGDEN)
C     Y9=G*Y8*STLIQM
C     Y9=Y9*0.002204852
C     Y10=Y9**(0.25)
C     AKU=Y7/Y10
C
C     Y11=FRG*AKU
C
C     IF(FRG.LT.X7) GO TO 500
C     IF(Y11.LT.Y3) GO TO 600
C     GO TO 800
C
C     DUKLER FLOW PATTERN
C
C
C
      X1I=XLDEN**(2.0)
      X2I=X1I*G*(DIAM**2.0)
      X3I=XLDEN-AGDEN
      X4I=X3I*STLIQM
      X4I=X4I*0.002204852
      X5I=X2I/X4I
      X6I=X5I**(0.25)
```

```
C
      W1I=XLDEN-AGDEN
      W2I=W1I*G*STLIQM*0.002204852
      W3I=XLDEN**(2.0)
      W4I=W2I/W3I
      W5I=W4I**(0.25)
      W6I=1.15*W5I
      W7I=3.0*VSG
      W8I=W7I-W6I
C
      Y1I=XLDEN-AGDEN
      Y2I=Y1I*G
      Y3I=Y2I/XLDEN
      Y4I=Y3I**(0.446)
      Y5I=STLIQM/XLDEN
      Y6I=Y5I**(0.089)
      Y7I=DIAM**(0.429)
      Y8I=Y6I*Y7I
      Y9I=ALIQV/XLDEN
      Y9I=Y9I**(.072)
      Y10I=Y8I/Y9I
      Y11I=Y4I*Y10I
      Y12I=Y11I*4.0
      Y12I=Y12I*4.61
C
      HH=0.25
      UGG=VSG/(1.0-HH)
      U1I=((G*DIAM)**(0.5))
      U2I=UGG/U1I
      U3I=35.5*U2I
CC
      U4I=((G*DIAM)**(0.5))
      U5I=VM/U4I
      U6I=U5I+0.22
      U7I=40.6*U6I
C
      V11=AGDEN**(0.5)
      V21=V11*VSG
      V31=XLDEN-AGDEN
      V41=STLIQM*G*V31
      V41=V41*0.002204852
      V51=V41**(0.25)
      V61=V21/V51
C
      IF(X6I.LE.4.36) GO TO 500
      IF(VSL.GE.W8I) GO TO 600
      IF(VM.GE.Y12I) GO TO 500
      IF(U3I.GE.U7I) GO TO 700
      IF(V61.GT.3.1) GO TO 800

C
```

```
C
C
C     REGION ONE
C
C
500   FP3=F3-(F4/AND)
C     WRITE (8,501) FP3
C01   FORMAT(T10,'FP3    =',T17,F20.9)
      S=F1+(F2*ANLV)+(FP3*((ANGV/(1+ANLV))**2))
C     WRITE (8,502) S
C02   FORMAT(T10,'S      =',T17,F20.9)
      VS=S/(1.983*((XLDEN/STLIQM)**0.25))
C     WRITE (8,503) VS
C03   FORMAT(T10,'VS     =',T17,F20.9)
      ASGL=VS-VSG-VSL
      HL=ASGL+SQRT(ASGL**2+4*VS*VSL)
      HL=HL/(2*VS)
      IF(HL.GT.1.0) GO TO 4
      IF(HL.LT.0.0) GO TO 6
      GO TO 5
4     HL=1.0
      GO TO 5
6     HL=0.0
C     WRITE (6,504) HL
C04   FORMAT(T10,'HL BUBL=',T17,F20.9)
5     REN=((1488*XLDEN*VSL*DIAM)/(ALIQV))
C     WRITE (6,505) REN
505   FORMAT(T10,'RENB   =',T17,F20.9)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C     WRITE (8,506) RR
C06   FORMAT(T10,'RR     =',T17,F20.9)
      IF(REN.GE.1000000) GO TO 531
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 532
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 533
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 534

531   F1A=0.005
      GO TO 540
532   F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
      GO TO 540
533   F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
      GO TO 540
534   F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
C
540   IF(REN.GE.1000000) GO TO 535
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 536
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 537
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 538
535   F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
```

```
      GO TO 539
536   F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
      GO TO 539
537   F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
      GO TO 539
538   F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
539   FF=F1B+(F1A-F1B)*((RR-0.0001)/0.0009)
      IF(REN.LE.2000) GO TO 16401
      GO TO 16402
16401 FF=64/REN
      GO TO 16405
16402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16406
      FF=FGI
C
C
C
C
C39   FF=F1B+(F1A-F1B)*((ALOG10(RR)-ALOG10(0.0001))/ALOG10(0.001))
C     WRITE (6,507) FF
507   FORMAT(T10,'FF    =',T17,F10.5)
C     WRITE(6,981)F1A,F1B,FF
981   FORMAT(3X,3(F9.6,2X))
C     MAKE FF1=FF
16405 FF1=FF
      FF1=FF
C     WRITE (6,508) FF1
508   FORMAT(T10,'FF1   =',T17,F10.5)
      RRR=(FF1*(VSG/VSL)*(AND**(2/3)))
      IF(RRR.GT.100)  GO TO 567
      GO TO 570
567   FF2=0.212
      GO TO 571
```

```
570    IF(RRR.LT.0.001) GO TO 12555
       GO TO 12556
12555 FF2=1.00
       GO TO 571
C      GET FF2 FROM FIG. 2.68
C      ************************************************************
C                                          FF2
C      ************************************************************
12556 A9=0.91634573
       B9=-0.50638149
       C9=-0.69957170
       D9=-0.45979184
       E9=-0.14394744
       F9=-0.01700007
       FFB9=B9*(ALOG10(RRR))
       FFC9=C9*((ALOG10(RRR))**2)
       FFD9=D9*((ALOG10(RRR))**3)
       FFE9=E9*((ALOG10(RRR))**4)
       FFF9=F9*((ALOG10(RRR))**5)
       FF2=A9+FFB9+FFC9+FFD9+FFE9+FFF9
C71    WRITE (6,569) RRR
C69    FORMAT(T10,'RRR   =',T17,F10.5)
C      WRITE (6,510) FF2
C10    FORMAT(T10,'FF2   =',T17,F10.5)
571    FF3=1+(FF1*(((VSG/VSL)/(50))**0.5))
C      WRITE(6,983)RRR,FF2
983    FORMAT(3X,2(F9.6,2X))
C      WRITE (8,511) FF3
C11    FORMAT(T10,'FF3   =',T17,F10.5)
       FW=((FF1*FF2)/(FF3))
C      WRITE (8,512) FW
C12    FORMAT(T10,'FW    =',T17,F10.5)
       GFR=(0.5*FW*(ANLV*(ANLV+ANGV))/AND)
       IF(GFR.LT.0.0) GFR=0.0
C      WRITE (6,513) GFR
513    FORMAT(T10,'GFRB  =',T17,F10.5)
C      WRITE(6,975)FF3,FW,GFR
C75    FORMAT(3X,3(F10.8,2X))
       GST=(HL+((1-HL)*(AGDEN/XLDEN)))
C      WRITE (6,514) GST
514    FORMAT(T10,'GSTB  =',T17,F10.5)
       GTOT=GFR+GST
C      WRITE (8,515) GTOT
C15    FORMAT(T10,'GTOT  =',T17,F10.5)
       DELPH=((GTOT*XLDEN)/144)
       DELPH2=DELPH*DELTAH
       DELPX=DELPH2
       DDD1=ABS(DELP-DELPH2)
       IF(DDD1.GT.0.1) GO TO 23765
C      WRITE (6,516) DELPH
516    FORMAT(T10,'DELPHP=',T17,F10.5)
```

```
      GO TO 900
C
C
C     REGION TWO
C
C
600   FP6=(0.029*AND)+F6
C     WRITE (8,601) FP6
C01   FORMAT(T10,'FP6    =',T17,F20.9)
      S=((1+F5)*((ANGV**0.982)+FP6))/((1+(F7*ANGV))**2)
C     WRITE (8,602) S
C02   FORMAT(T10,'S      =',T17,F20.9)
      VS=S/(1.983*((XLDEN/STLIQM)**0.25))
C     WRITE (8,603) VS
C03   FORMAT(T10,'VS     =',T17,F20.9)
      ASGL=VS-VSG-VSL
      HL=ASGL+SQRT(ASGL**2+4*VS*VSL)
      HL=HL/(2*VS)
      IF(HL.GT.1.0) GO TO 1
      IF(HL.LT.0.0) GO TO 3
      GO TO 2
1     HL=1.0
      GO TO 2
3     HL=0.0
C     WRITE(6,975)HL,XLDEN
975   FORMAT(3X,2(F12.8,2X))
C     WRITE (6,604) HL
604   FORMAT(T10,'HL SLUG=',T17,F20.9)
2     REN=((1488*XLDEN*VSL*DIAM)/(ALIQV))
C     WRITE (6,605) REN
605   FORMAT(T10,'RENS   =',T17,F20.9)
C     FIND FF
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C     WRITE (8,606) RR
C06   FORMAT(T10,'RR     =',T17,F10.5)
      IF(REN.GE.1000000) GO TO 631
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 632
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 633
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 634

631   F1A=0.005
      GO TO 640
632   F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
      GO TO 640
633   F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
      GO TO 640
634   F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
C
C
```

```
C
640   IF(REN.GE.1000000) GO TO 635
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 636
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 637
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 638
635   F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
      GO TO 639
636   F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
      GO TO 639
637   F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
      GO TO 639
638   F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
639   FF=F1B+(F1A-F1B)*((RR-0.0001)/0.0009)
C39   FF=F1B+(F1A-F1B)*((ALOG10(RR)-ALOG10(0.0001))/ALOG10(0.001))
      IF(REN.LE.2000) GO TO 16801
      GO TO 16802
16801 FF=64/REN
      GO TO 16805
16802 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16806 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16805
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16806
      FF=FGI
C
C
C
C
C     WRITE(6,982)FF
982   FORMAT(3X,1(F9.6,2X))
C     WRITE (8,607) FF
C07   FORMAT(T10,'FF    =',T17,F10.5)
C     ASSUME FF1=FF
16805 FF1=FF
      FF1=FF
C     WRITE (6,608) FF1
608   FORMAT(T10,'FF1   =',T17,F10.5)
```

```
      RRR=(FF1*(VSG/VSL)*(AND**(2/3)))
      D1=VSG/VSL
      D2=AND**(2/3)
      RRR=FF1*D1*D2
C
C
      IF(RRR.GT.100)  GO TO 667
      GO TO 670
667   FF2=0.212
      GO TO 671
670   IF(RRR.LT.0.001) GO TO 687
      GO TO 686
687   FF2=1.00
      GO TO 671
C     GET FF2 FROM FIG. 2.68
C     ***************************************************************
C                                  FF2
C     ***************************************************************
686   A9=0.91634573
      B9=-0.50638149
      C9=-0.69957170
      D9=-0.45979184
      E9=-0.14394744
      F9=-0.01700007
      FFB9=B9*(ALOG10(RRR))
      FFC9=C9*((ALOG10(RRR))**2)
      FFD9=D9*((ALOG10(RRR))**3)
      FFE9=E9*((ALOG10(RRR))**4)
      FFF9=F9*((ALOG10(RRR))**5)
      FF2=A9+FFB9+FFC9+FFD9+FFE9+FFF9
C71   WRITE (6,609) RRR
609   FORMAT(T10,'RRR   =',T17,F10.5)
C     WRITE (8,610) FF2
C10   FORMAT(T10,'FF2   =',T17,F10.5)
671   FF3=1+(FF1*(((VSG/VSL)/(50))**0.5))
      FW1=VSG/VSL
      FW2=FW1/50
      FW3=FW2**0.5
      FW4=FW3*FF1
      FF3=1+FW4
C
C     WRITE (8,611) FF3
C11   FORMAT(T10,'FF3   =',T17,F10.5)
      FW=((FF1*FF2)/(FF3))
C     WRITE(6,984)RRR,FF1,FF2,FF3
984   FORMAT(3X,4(F12.6,2X))
C     WRITE (6,612) FW
612   FORMAT(T10,'FW    =',T17,F10.5)
      GFR=(0.5*FW*(ANLV*(ANLV+ANGV))/AND)
      AC1=0.5*FW
      AC2=VSL**2
```

```
      AC3=AC1*AC2
      AC4=32.174*DIAM
      AC5=AC3/AC4
      AC6=VSG/VSL
      AC7=AC6+1
      GFR=AC5*AC7
C
C
C
C
C
      IF(GFR.LT.0.0) GFR=0.0
      FGR=GFR*XLDEN
      FGR=FGR/144
C     WRITE (6,613) FGR
613   FORMAT(T10,'FGR   =',T17,F10.5)
      XX5=GOR-RSAVG
      XX6=(XX5*OILRTE)/1000
C     WRITE (6,888) XX6
888   FORMAT(T10,'FREGS=',T17,F10.5)

C     WRITE(6,976)FW,ANLV,ANGV,AND
976   FORMAT(3X,4(F13.8,2X))
      GST=(HL+((1-HL)*(AGDEN/XLDEN)))
      XCC=GST*XLDEN/144
C     WRITE (6,614) XCC
614   FORMAT(T10,'XCCS   =',T17,F10.5)

      GTOT=GFR+GST
C     WRITE (8,615) GTOT
C15   FORMAT(T10,'GTOT   =',T17,F10.5)
      DELPH=((GTOT*XLDEN)/144)
      DELPH1=DELPH*DELTAH
      DELPX=DELPH1
      DDD1=ABS(DELP-DELPH1)
      IF(DDD1.GT.0.01) GO TO 23765
C
C     WRITE (6,616) DELPH
616   FORMAT(T10,'DELPHS=',T17,F10.5)
      GO TO 900
C
C
C     TRANSITION REGION
C
C
700   ANGV2=53
      FP6=(0.029*AND)+F6
C     WRITE (8,701) FP6
C01   FORMAT(T10,'FP6     =',T17,F20.9)
      S=((1+F5)*((ANGV2**0.982)+FP6))/(1+((F7*ANLV)**2))
C     WRITE (8,702) S
```

```
C02     FORMAT(T10,'S       =',T17,F20.9)
        VS=S/(1.983*((XLDEN/STLIQM)**0.5))
C       WRITE (8,703) VS
C03     FORMAT(T10,'VS      =',T17,F20.9)
        ASGL=VS-VSG-VSL
        HL=ASGL+SQRT(ASGL**2+4*VS*VSL)
        HL=HL/(2*VS)
        IF(HL.GT.1.0) GO TO 7
        IF(HL.LT.0.0) GO TO 9
        GO TO 8
7       HL=1.0
        GO TO 8
9       HL=0.0
C       WRITE (6,704) HL
C04     FORMAT(T10,'HL TRAN=',T17,F20.9)
8       REN=((1488*XLDEN*VSL*DIAM)/(ALIQV))
C       WRITE (6,705) REN
705     FORMAT(T10,'RENT1   =',T17,F20.9)
C       FIND FF
C       CALCULATE FRICTION FACTOR
        EE=.00015
C       RR=EE*12/DIAM
        RR=EE/DIAM
C       WRITE (8,706) RR
C06     FORMAT(T10,'RR      =',T17,F10.5)
        IF(REN.GE.1000000) GO TO 731
        IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 732
        IF(REN.GT.10000.AND.REN.LT.100000) GO TO 733
        IF(REN.GT.3600.AND.REN.LT.10000) GO TO 734

731     F1A=0.005
        GO TO 798
732     F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
        GO TO 798
733     F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
        GO TO 798
734     F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
798     CONTINUE
C
C
C
        IF(REN.GE.1000000) GO TO 735
        IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 736
        IF(REN.GT.10000.AND.REN.LT.100000) GO TO 737
        IF(REN.GT.3600.AND.REN.LT.10000) GO TO 738
735     F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
        GO TO 739
736     F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
        GO TO 739
737     F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
        GO TO 739
```

```
738    F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
739    FF=F1B+(F1A-F1B)*((RR-0.0001)/0.001)
C      WRITE (8,707) FF
C07    FORMAT(T10,'FF    =',T17,F10.5)
C      ASSUME FF1=FF
       IF(REN.LE.2000) GO TO 17401
       GO TO 17402
17401  FF=64/REN
       GO TO 17405
17402  I=1
       FGI=REN**0.32
       FGI=0.5/FGI
       FGI=0.0056+FGI

17406  B11=FGI**0.5
       B12=B11*REN
       B13=9.34/B12
       B14=RR+B13
       B15=ALOG10(B14)
       B16=B15*2.0
       DEN=1.14-B16
       FF=(1./DEN)
       FF=FF**2
       DIFF=ABS(FGI-FF)
       IF(DIFF.LE.0.0001) GO TO 17405
       FGI=(FGI+FF)/2.0
       I=I+1
       IF(I.LT.10) GO TO 17406
       FF=FGI
17405  FF1=FF
C      WRITE (6,708) FF1
708    FORMAT(T10,'FF1   =',T17,F10.5)
       RRR=(FF1*(VSG/VSL)*(AND**(2/3)))
       IF(RRR.GT.100)  GO TO 757
       GO TO 756
757    FF2=0.212
       GO TO 758
C56    IF(RRR.LT.0.001) FF2=1.05
C      GO TO 758
756    IF(RRR.LT.0.001) GO TO 12557
       GO TO 12558
12557  FF2=1.05
       GO TO 758
C
C
C
C
C
C      GET FF2 FROM FIG. 2.68
C      **********************************************************
C                                 FF2
```

```
C     ************************************************************
12558 A9=0.91634573
      B9=-0.50638149
      C9=-0.69957170
      D9=-0.45979184
      E9=-0.14394744
      F9=-0.01700007
      FFB9=B9*(ALOG10(RRR))
      FFC9=C9*((ALOG10(RRR))**2)
      FFD9=D9*((ALOG10(RRR))**3)
      FFE9=E9*((ALOG10(RRR))**4)
      FFF9=F9*((ALOG10(RRR))**5)
      FF2=A9+FFB9+FFC9+FFD9+FFE9+FFF9
C58   WRITE (8,709) RRR
C09   FORMAT(T10,'RRR   =',T17,F10.5)
C     WRITE (8,710) FF2
C10   FORMAT(T10,'FF2   =',T17,F10.5)
758   FF3=1+(FF1*(((VSG/VSL)/(50))**0.5))
C     WRITE (8,711) FF3
C11   FORMAT(T10,'FF3   =',T17,F10.5)
      FW=((FF1*FF2)/(FF3))
C     WRITE (8,712) FW
C12   FORMAT(T10,'FW    =',T17,F10.5)
      GFR2=(0.5*FW*(ANLV*(ANLV+ANGV2))/AND)
      IF(GFR2.LT.0.0) GFR2=0.0
C     WRITE (6,713) GFR2
713   FORMAT(T10,'GFR2  =',T17,F10.5)
      GST2=(HL+((1-HL)*(AGDEN/XLDEN)))
C     WRITE (6,714) GST2
714   FORMAT(T10,'GST2  =',T17,F10.5)
      GTOT2=GFR2+GST2
C     WRITE (6,715) GTOT2
715   FORMAT(T10,'GTOT2 =',T17,F10.5)
C
C
C     AT ANGV3
C
C
      ANGV3=85
      S=0.0
      VS=0.0
      HL=((1/(1+(VSG/VSL))))
      IF(HL.GT.1.0) GO TO 61
      IF(HL.LT.0.0) GO TO 63
      GO TO 62
61    HL=1.0
      GO TO 62
63    HL=0.0
C2    WRITE (8,716) HL
C16   FORMAT(T10,'HL     =',T17,F20.9)
C     CALCULATE THE MOLECULAR WT OF THE GAS
```

```
62    GMWT=SPGGAS*29
C     WRITE (8,717) GMWT
C17   FORMAT(T10,'GMWT  =',T17,F10.5)
C     CALCULATE VISCOSITY OF THE GAS
      XXX=3.5+986/(TAVG+460)+0.01*GMWT
      GAMMA=2.4-0.2*XXX
      AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
     *(209+19*GMWT+(TAVG+460))
      AGASVI=AKKK*0.0001*EXP(XXX*((AGDEN*454/30.8**3)**GAMMA))
C     WRITE (6,718) AGASVI
718   FORMAT(T10,'AGASVI=',T17,F10.5)
      REN=((1488*AGDEN*VSG*DIAM)/(AGASVI))
C     WRITE (6,719) REN
719   FORMAT(T10,'RENT2 =',T17,F20.9)
      RAW=(AGDEN/XLDEN)
C     WRITE (8,720) RAW
C20   FORMAT(T10,'RAW   =',T17,F10.5)
      EEE=(0.05*DIAM)
C     WRITE (8,721) EEE
C21   FORMAT(T10,'EEE   =',T17,F10.5)
      IF(EE.GT.EEE) GO TO 750
C     FIND FF FROM MOODY DIAGRAM
C     FIND FF
C     CALCULATE FRICTION FACTOR
      EE=.00015
C     RR=EE*12/DIAM
      RR=EE/DIAM
C     WRITE (8,722) RR
C22   FORMAT(T10,'RR    =',T17,F10.5)
      IF(REN.GE.1000000) GO TO 761
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 762
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 763
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 764

761   F1A=0.005
      GO TO 799
762   F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
      GO TO 799
763   F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
      GO TO 799
764   F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
799   CONTINUE
C
C
C
      IF(REN.GE.1000000) GO TO 765
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 766
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 767
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 768
765   F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
      GO TO 769
```

```
766   F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
      GO TO 769
767   F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
      GO TO 769
768   F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
769   FF=F1B+(F1A-F1B)*((RR-0.0001)/0.001)
      IF(REN.LE.2000) GO TO 18401
      GO TO 18402
18401 FF=64/REN
      GO TO 18405
18402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

18406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 18405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 18406
      FF=FGI
C     WRITE (8,723) FF
C23   FORMAT(T10,'FF    =',T17,F10.5)
18405 FF1=FF
C     WRITE (6,724) FF1
724   FORMAT(T10,'FF1   =',T17,F10.5)
      FW=FF1
C     WRITE (8,725) FW
C25   FORMAT(T10,'FW    =',T17,F10.5)
      GO TO 770
750   SSSS=(0.027*EE/DIAM)
C     WRITE (8,726) SSSS
C26   FORMAT(T10,'SSSS  =',T17,F10.5)
      FF1=((1/((4*(ALOG10(SSSS)))**2))+((0.067*((EE/DIAM)**1.73))))
C     WRITE (8,727) FF1
C27   FORMAT(T10,'FF1   =',T17,F10.5)
C     VSG=((VSG*((DIAM)**2)/(DIAM-EE)))
      FW=FF1
770   GFR3=(0.5*FW*RAW*((ANGV3**2)/(AND)))
      IF(GFR3.LT.0.0) GFR3=0.0
C     WRITE (6,728) GFR3
728   FORMAT(T10,'GFR3  =',T17,F10.5)
```

```
      GST3=(HL+(1-HL)*(AGDEN/XLDEN))
C     WRITE (6,729) GST3
729   FORMAT(T10,'GST3  =',T17,F10.5)
C     GTOT3=((GST3+GFR3)/(1-((XLDEN*VSL)+((AGDEN*VSG)*(VSG/PAVG)))))
      Y1=GFR3+GST3
      Y2=AGDEN*VSG
      Y3=XLDEN*VSL
      Y4=Y2+Y3
      Y5A=PAVG*144*32.174
      Y5=VSG/Y5A
      Y6=Y4*Y5
      Y7=1-Y6
      GTOT3=Y1/Y7
C     WRITE(13,19043)VSG,ANGV,ANGV2,ANGV3
19043 FORMAT(3X,4(F9.2,2X))
C     WRITE (6,730) GTOT3
730   FORMAT(T10,'GTOT3 =',T17,F10.5)
      GTOT=((((ANGV3-ANGV)/(ANGV3-ANGV2))*(GTOT2))+(((ANGV-ANGV2)/
     *(ANGV3-ANGV2))*(GTOT3)))
      DELPH=((GTOT*XLDEN)/144)
C     WRITE (6,740) DELPH
740   FORMAT(T10,'DELPHT=',T17,F10.5)
      GO TO 900
C
C
C     REGION THREE
C
C
800   S=0.0
      VS=0.0
      HL=((1/(1+(VSG/VSL))))
      IF(HL.GT.1.0) GO TO 51
      IF(HL.LT.0.0) GO TO 53
      GO TO 52
51    HL=1.0
      GO TO 52
53    HL=0.0
C2    WRITE (6,801) HL
C01   FORMAT(T10,'HL MIST=',T17,F20.9)
C     CALCULATE THE MOLECULAR WT OF THE GAS
52    GMWT=SPGGAS*29
C     WRITE (8,802) GMWT
C02   FORMAT(T10,'GMWT  =',T17,F10.5)
C     CALCULATE VISCOSITY OF THE GAS
      XXX=3.5+986/(TAVG+460)+0.01*GMWT
      GAMMA=2.4-0.2*XXX
      AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
     *(209+19*GMWT+(TAVG+460))
      AGASVI=AKKK*0.0001*EXP(XXX*((AGDEN*454/30.8**3)**GAMMA))
C     WRITE (8,803) AGASVI
C03   FORMAT(T10,'AGASVI=',T17,F10.5)
```

```
      REN=((1488*AGDEN*VSG*DIAM)/(AGASVI))
C     WRITE (6,804) REN
804   FORMAT(T10,'RENM   =',T17,F20.9)
      RAW=(AGDEN/XLDEN)
C     WRITE (8,805) RAW
C05   FORMAT(T10,'RAW    =',T17,F10.5)
      EEE=(0.05*DIAM)
C     WRITE (8,806) EEE
C06   FORMAT(T10,'EEE    =',T17,F10.5)
      IF(EE.GT.EEE) GO TO 850
C     FIND FF FROM MOODY DIAGRAM
C     FIND FF
C     CALCULATE FRICTION FACTOR
      EE=.00015
C     RR=EE*12/DIAM
      RR=EE/DIAM
C     WRITE (8,807) RR
C07   FORMAT(T10,'RR     =',T17,F10.5)
      IF(REN.GE.1000000) GO TO 831
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 832
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 833
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 834

831   F1A=0.005
      GO TO 898
832   F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
      GO TO 898
833   F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
      GO TO 898
834   F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
898   CONTINUE
C
C
C
      IF(REN.GE.1000000) GO TO 835
      IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 836
      IF(REN.GT.10000.AND.REN.LT.100000) GO TO 837
      IF(REN.GT.3600.AND.REN.LT.10000) GO TO 838
835   F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
      GO TO 839
836   F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
      GO TO 839
837   F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
      GO TO 839
838   F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
839   FF=F1B+(F1A-F1B)*((RR-0.0001)/0.001)
      IF(REN.LE.2000) GO TO 19401
      GO TO 19402
19401 FF=64/REN
      GO TO 19405
19402 I=1
```

```
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

19406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 19405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 19406
      FF=FGI
C     WRITE (8,808) FF
C08   FORMAT(T10,'FF    =',T17,F10.5)
19405 FF1=FF
C     WRITE (8,809) FF1
C09   FORMAT(T10,'FF1   =',T17,F10.5)
      FW=FF1
C     WRITE (8,810) FW
C10   FORMAT(T10,'FW    =',T17,F10.5)
      GO TO 870
850   SSSS=(0.027*EE/DIAM)
C     WRITE (8,811) SSSS
C11   FORMAT(T10,'SSSS  =',T17,F10.5)
      FF1=((1/((4*(ALOG10(SSSS)))**2))+((0.067*((EE/DIAM)**1.73))))
C     WRITE (8,812) FF1
C12   FORMAT(T10,'FF1   =',T17,F10.5)
C     VSG=((VSG*((DIAM)**2)/(DIAM-EE)))
      FW=FF1
870   GFR=(0.5*FW*RAW*((ANGV**2)/(AND)))
      IF(GFR.LT.0.0) GFR=0.0
C     WRITE (6,813) GFR
813   FORMAT(T10,'GFRM  =',T17,F10.5)
      GST=(HL+(1-HL)*(AGDEN/XLDEN))
C     WRITE (8,814) GST
814   FORMAT(T10,'GSTM  =',T17,F10.5)
C     GTOT=((GST+GFR)/(1-((XLDEN*VSL)+((AGDEN*VSG)*(VSG/PAVG)))))
      Y1=GFR+GST
      Y2=AGDEN*VSG
      Y3=XLDEN*VSL
      Y4=Y2+Y3
      Y5A=(PAVG*144*32.174)
      Y5=VSG/Y5A
      Y6=Y4*Y5
```

```
      Y7=1-Y6
      GTOT=Y1/Y7
C     WRITE (8,815) GTOT
815   FORMAT(T10,'GTOT  =',T17,F10.5)
      DELPH=((GTOT*XLDEN)/144)
C     WRITE (6,816) DELPH
816   FORMAT(T10,'DELPHM=',T17,F20.7)
900   DELPP=DELTAH*DELPH
C
C     CALCULATE TOTAL DEPTH
      DEPTH1=DEPTH1+DELTAH
      P2=P1+DELPP
      IF(DEPTH1.GE.TOTDEP) GO TO 1831
      GO TO 1832
1831  DEPTH2=DEPTH1-TOTDEP
      DDD1=DEPTH2/DELTAH
      DDD2=DDD1*DELPP
      P2=P2-DDD2
      DEPTH1=DEPTH1-DEPTH2
1832  IF(IPROF.EQ.1) WRITE(13,908)DEPTH1,P2
908   FORMAT(3X,2(F9.2,2X))
C
      FGE=DEPTH1-TOTDEP
      IF(FGE.EQ.0.0) GO TO 1000
C
C     WRITE(6,908)DEPTH1,P2
C08   FORMAT(3X,2(F9.2,2X))
C     ASSUME P1 EQUAL TO P2 AND DEPTH1 EQUAL TO DEPTH2 AND ITERATE
      P1=P2
      T1=T2
C     DEPTH1=CDEPTH
      GO TO 11
1000  BHFP=P2
      RETURN
      END
```

```
C     ************************************************
C     *                                              *
C     *        KABIR & HASAN CORRELATION             *
C     *                                              *
C     ************************************************
C     KABIR
      SUBROUTINE KABIR(VS,RESTMP,SURTMP,P1,DEPTH1,OILRTE,WTRRTE,DIMTB,
     &API,GOR,DIMTSG,DIMTBG,SPGWTR,SPGGAS,STNOIL,STNWTR,BW,EE,
     &DELP,DELTAH,G,GC,T1,TOTDEP,DIMTB2,DEPTB2,BHFP,IPROF)
C
C     STEP : 1 CALCULATE SPECIFIC GRAVITY OF OIL
C
      SPGOIL=141.5/(131.5+API)
C     WRITE (6,101) SPGOIL
C01   FORMAT(T10,' SPGOIL =',T17,F10.5)
C
C     STEP : 2 CALCULATE GLR WOR WCUT TOTAL LIQUID AND FLUID GRADIENT
C
      GLR=GOR*(OILRTE/(OILRTE+WTRRTE))
C     WRITE (6,102) GLR
C02   FORMAT(T10,' GLR =',T17,F10.5)
      WOR=WTRRTE/OILRTE
      DEPTH1=0
C     WRITE (6,103) WOR
C03   FORMAT(T10,' WOR =',T17,F10.5)
      WCUT=WTRRTE/(OILRTE+WTRRTE)
C     WRITE (6,104) WCUT
C04   FORMAT(T10,' WCUT =',T17,F10.5)
      TOTLIQ=OILRTE+WTRRTE
C     WRITE (6,105) TOTLIQ
C05   FORMAT(T10,' TOTLIQ =',T17,F10.1)
      APRXGD=.433*WCUT+SPGOIL*.433*(1.0-WCUT)
C     WRITE (6,106) APRXGD
C06   FORMAT(T10,' APRXGD =',T17,F10.5)
C     WRITE (6,107) DIAM
C07   FORMAT(T10,' DIAM =',T17,F10.5)
C
C     STEP : 4 CALCULATE MASS ASSOCIATED WITH 1 STB OF LIQUID
C
      AMASS=((SPGOIL*350.0)*(1.0-WCUT))
      BMASS=SPGWTR*350.0*WCUT
      CMASS=0.0764*GLR*SPGGAS
      TM=AMASS+BMASS+CMASS
C     WRITE (6,108) TM
C08   FORMAT(T10,' TM    =',T17,F10.5)
C
C     STEP : 5 CALCULATE MASS FLOW RATE
C
      W1=TM*TOTLIQ
C     WRITE (6,109) W1
C09   FORMAT(T10,' W1    =',T17,F10.0)
```

```
C
C     STEP : 6 CALCULATE TEMPERATURE GRADIENT
C
      TEMGRD=(RESTMP-SURTMP)/TOTDEP
C     WRITE (6,110) TEMGRD
C10   FORMAT(T10,' TEMGRD=',T17,F10.5)
C     WRITE (6,111) T1
C11   FORMAT(T10,' T1    =',T17,F10.5)
C
C     STEP : 7 CALCULATE AVERAGE TEMP AND AVERAGE PRESS
C
11    DELP=DELTAH*APRXGD
      DELP=25
      NITR=0
      GO TO 23457
23456 DELP=DELPP
C     STEP : 3 CALCULATE HYDRAULIC DIAMETER
C              DIMTSG: INSIDE DIAMETER OF THE CASING
C              DIMTBG: OUTSIDE DIAMETER OF THE TUBING
C              DIMTB : INSIDE DIAMETER OF THE TUBING
C     CALCULATE THE AREA OF FLOW
C
23457 IF(DIMTSG.EQ.0.0) GO TO 12
      AREA=(22/7)*((DIMTSG**2-DIMTBG**2)/4)
      GO TO 14
12    IF(DEPTH1.LE.DEPTB2) GO TO 938
      DIAM=DIMTB2
      GO TO 14001
938   DIAM=DIMTB
14001 AREA=22*DIAM**2/(4*7)
14    CONTINUE
C     WRITE (6,112) DELP
C12   FORMAT(T10,' DELP  =',T17,F10.5)
      T2=T1+TEMGRD*DELTAH
C     WRITE (6,113) T2
C13   FORMAT(T10,' T2    =',T17,F10.5)
C13   TAVG=(T1+T2)/2
      TAVG=(T1+T2)/2
C     WRITE (6,114) TAVG
C14   FORMAT(T10,' TAVG  =',T17,F10.5)
      P2=P1+DELP
C     WRITE (6,115) P2
C15   FORMAT(T10,' P2    =',T17,F20.5)
C     WRITE (6,116) P1
C16   FORMAT(T10,' P1    =',T17,F20.5)
      PAVG=(P1+P2)/2+14.7
C     PAVG=(P1+P2)/2
C     WRITE (6,117) PAVG
C17   FORMAT(T10,' PAVG  =',T17,F20.5)
C
C     STEP : 8 CALCULATE SOLUTION GAS AT AVGP P1 P2
```

```
C
19     X1=PAVG/18
       X2=(10**((.0125*(API))))
       X3=(10**(0.00091*(TAVG)))
       X4=((X1*(X2/X3))**(1/0.83))
       RSAVG=SPGGAS*X4
       IF(RSAVG.LE.GOR) GO TO 1111
       RSAVG=GOR
C111   WRITE (6,118) RSAVG
C18    FORMAT(T10,' RSAVG =',T17,F10.5)
C      P1
C      X5=P1/18
1111   X5=P1/18
       X6=(10**((.0125*(API))-(0.00091*T1)))
       X7=(((X5*X6))**(1/0.83))
       RS1=SPGGAS*X7
       IF(RS1.LE.GOR) GO TO 20
       RS1=GOR
C0     WRITE (6,119) RS1
C19    FORMAT(T10,' RS1   =',T17,F10.5)
C      P2
C      X9=P2/18
20     X9=P2/18
       X10=(10**((.0125*(API))-(0.00091*T2)))
       X11=(((X9*X10))**(1/0.83))
       RS2=SPGGAS*X11
       IF(RS2.LE.GOR) GO TO 21
       RS2=GOR
C1     WRITE (6,120) RS2
C20    FORMAT(T10,' RS2   =',T17,F10.5)
C      CONTINUE
C
C      STEP : 9 CALCULATE FORM. VOL. FACTOR AT PAVG,TAVG P1,T1 P2,T2
C
21     FAVG=((RSAVG*((SPGGAS/SPGOIL)**0.5))+(1.25*TAVG))
C      WRITE(6,990)FAVG
C90     FORMAT(3X,(F8.2,3X))
       BOAVG=(0.972+((0.000147)*((FAVG**1.175))))
C      WRITE (6,121) BOAVG
C21    FORMAT(T10,' BOAVG =',T17,F10.5)
       F1=((RS1*((SPGGAS/SPGOIL)**0.5))+(1.25*T1))
       BO1=(0.972+((0.000147)*((F1**1.175))))
C      WRITE (6,122) BO1
C22    FORMAT(T10,' BO1   =',T17,F10.5)
       F2=((RS2*((SPGGAS/SPGOIL)**0.5))+(1.25*T2))
       BO2=(0.972+((0.000147)*((F2**1.175))))
C      WRITE (6,123) BO2
C23    FORMAT(T10,' BO2   =',T17,F10.5)
C
C      STEP : 10 CALCULATE THE DENSITY OF THE LIQUID PHASE
C
```

```
      G1=(SPGOIL*(62.4)+(RSAVG*SPGGAS*(0.0764))/(5.614))
      G2=((G1/BOAVG)*(1-WCUT))
      G3=((SPGWTR)*(62.4)*(WCUT))
      XLDEN=(G2+G3)
C     WRITE (6,124) XLDEN
C24   FORMAT(T10,'XLDEN  =',T17,F10.5)
C     AT P1
      G4=(SPGOIL*(62.4)+(RS1*SPGGAS*(0.0764))/(5.614))
      G5=((G4/BO1)*(1-WCUT))
      G6=((SPGWTR)*(62.4)*(WCUT))
      DEN1=(G5+G6)
C     WRITE (6,125) DEN1
C25   FORMAT(T10,' DEN1  =',T17,F10.5)
C     AT P2
      G7=(SPGOIL*(62.4)+(RS2*SPGGAS*(0.0764))/(5.614))
      G8=((G7/BO2)*(1-WCUT))
      G9=((SPGWTR)*(62.4)*(WCUT))
      DEN2=(G8+G9)
C     WRITE (6,126) DEN2
C26   FORMAT(T10,' DEN2  =',T17,F10.5)
C     CALCULATE GAS COMPRESSIBILITY FACTOR AT PAVG,TAVG P1,T1 P2,T2
      PPC=(709.604-58.718*(SPGGAS))
      TPC=(170.491+307.344*(SPGGAS))
      APR=PAVG/PPC
      ATR=(TAVG+460)/TPC
      PR1=(P1+14.7)/PPC
      TR1=(T1+460)/TPC
      PR2=(P2+14.7)/PPC
      TR2=(T2+460)/TPC
C     COEFFICIENTS
      A1=0.31506237
      A2=-1.04670990
      A3=-0.57832729
      A4=0.53530771
      A5=-0.61232032
      A6=-0.10488813
      A7=0.68157001
      A8=0.68446549
C     AT PAVG TAVG  ASSUME Z=1.0
      PR=APR
      TR=ATR
      AZ=1.0
 15   CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 30
      AZ=CZ
      GO TO 15
```

```
30    AVGZ=CZ
C     WRITE (6,127) AVGZ
C27   FORMAT(T10,' AVGZ  =',T17,F10.5)
C     AT P1 T1
      PR=PR1
      TR=TR1
      AZ=1.0
25    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 35
      AZ=CZ
      GO TO 25
35    Z1=CZ
C     WRITE (6,128) Z1
C28   FORMAT(T10,' Z1    =',T17,F10.5)
C     AT P2 T2
      PR=PR2
      TR=TR2
      AZ=1.0
45    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 40
      AZ=CZ
      GO TO 45
40    Z2=CZ
C     WRITE (6,129) Z2
C29   FORMAT(T10,' Z2    =',T17,F10.5)
C
C     CALCULATE AVERAGE GAS DENSITY
C
      AGDEN=SPGGAS*0.0764*(PAVG/14.7)*(520/(TAVG+460))*(1/AVGZ)
C     WRITE (6,130) AGDEN
C30   FORMAT(T10,' AGDEN =',T17,F10.5)
C
C     CALCULATE AVERAGE VISCOSITY OF OIL
C
      S=3.0324-0.02023*(API)
      Y=10**(S)
      X=Y*(T1**(-1.163))
      ADOILV=(10**X)-1
      A=10.715*((RSAVG+100)**(-0.515))
      B=5.44*((RSAVG+150)**(-0.338))
      AOILV=(A*(ADOILV**B))
```

```
C     WRITE (6,131) AOILV
C31   FORMAT(T10,'AOILV =',T17,F10.5)
C
C     CALCULATE AVERAGE WATER VISCOSITY
C
      AWTRV=EXP(1.003-1.479E-2*TAVG+1.982E-5*(TAVG**(-2)))
C     WRITE (6,132) AWTRV
C32   FORMAT(T10,'AWTRV =',T17,F10.5)
C
C     CALCULATE LIQUID MIXTURE VISCOSITY
C
      ALIQV=AOILV*(1-WCUT)+AWTRV*(WCUT)
C     WRITE (6,133) ALIQV
C33   FORMAT(T10,'ALIQV =',T17,F10.5)
C
C     CALCULATE LIQUID MIXTURE SURFACE TENSION
C
      STLIQM=STNOIL*(1-WCUT)+STNWTR*(WCUT)
C     WRITE (6,134) STLIQM
C34   FORMAT(T10,'STLIQM=',T17,F10.5)
C
C     CALCULATE LIQUID VISCOSITY NUMBER
C
      VLN=0.15726*ALIQV*((1/(XLDEN*STLIQM**3))**0.25)
C     WRITE (6,135) VLN
C35   FORMAT(T10,'VLN   =',T17,F10.5)
C     CALCULATE VISCOSITY NUMBER CORRECTION FACTOR CNL
      A = 0.01001681
      B = -0.01522753
      C = -0.03911264
      D = -0.02739780
      E = -0.007981444
      F = -0.000842104
C     CNLB = B*(ALOG10(VLN))
C     CNLC = C*((ALOG10(VLN))**2)
C     CNLD = D*((ALOG10(VLN))**3)
C     CNLE = E*((ALOG10(VLN))**4)
C     CNLF = F*((ALOG10(VLN))**5)
C     CNL = A+CNLB+CNLC+CNLD+CNLE+CNLF
C     WRITE (6,136) CNL
C36   FORMAT(T10,'CNL   =',T17,F10.5)
C
C     CALCULATE SUPERFICIAL LIQUID VELOCITY
C
      BW=1.0
      VSL=5.61*((OILRTE+WTRRTE)/(86400*AREA))
     **(BOAVG*(1-WCUT)+BW*(WCUT))
C     WRITE (6,138) VSL
C38   FORMAT(T10,'VSL=',T17,F10.5)
      VSL1=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO1*(1-WCUT)+BW*(WCUT))
C     WRITE (6,139) VSL1
```

```
C39   FORMAT(T10,'VSL1  =',T17,F10.5)
      VSL2=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO2*(1-WCUT)+BW*(WCUT))
C     WRITE (6,140) VSL2
C40   FORMAT(T10,'VSL2  =',T17,F10.5)
C
C     CALCULATE LIQUID VELOCITY NUMBER
C
      ANLV=1.938*VSL*((XLDEN/STLIQM)**0.25)
C     WRITE (6,141) ANLV
C41   FORMAT(T10,'ANLV  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT PAVG AND TAVG
C
      VSG=((OILRTE+WTRRTE)*(GLR-RSAVG*(1-WCUT))/(86400*AREA))*
     *(14.7/(PAVG+14.7))*((TAVG+460)/520)*(AVGZ)
C     WRITE (6,142) VSG
C42   FORMAT(T10,'VSG  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P1 AND T1
C
      VSG1=((OILRTE+WTRRTE)*(GLR-RS1*(1-WCUT))/(86400*AREA))*
     *(14.7/P1)*((T1+460)/520)*(Z1)
C     WRITE (6,143) VSG1
C43   FORMAT(T10,'VSG1  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P2 AND T2
C
      VSG2=((OILRTE+WTRRTE)*(GLR-RS2*(1-WCUT))/(86400*AREA))*
     *(14.7/P2)*((T2+460)/520)*(Z2)
C     WRITE (6,144) VSG2
C44   FORMAT(T10,'VSG2  =',T17,F10.5)
C
C     CALCULATE GAS VELOCITY NUMBER

      ANGV=1.938*VSG*((XLDEN/STLIQM)**0.25)
C     WRITE (6,145) ANGV
C45   FORMAT(T10,'ANGV  =',T17,F10.5)
C     ***************************************************************
C               ****************************************
C     ***************************************************************
      AND=120.872*(DIAM)*((XLDEN/STLIQM)**0.5)
C     ***********************************************************
C     *                                                         *
C     *                REGIONS BOUNDARIES                       *
C     *                                                         *
C     ***********************************************************
C
      VM=VSG+VSL
      T=(XLDEN-AGDEN)/XLDEN
      TT=G*DIAM*T
      TTT=TT**0.5
```

```
      VTT=0.35*TTT
C     WRITE (6,6555) VTT
C555  FORMAT(T10,'VTT    =',T17,F20.10)
C
      V=XLDEN-AGDEN
      VV=XLDEN**2
      VVV=V/VV
      VVVV=G*STLIQM*VVV
      VVVVV=VVVV**0.25
      VT=1.53*VVVVV
C
C     CONVERSION FACTOR=0.216693
C
      VT=VT*0.216693
C
      CO=1.2
C
      E=CO*VM
      XX=E+VT
      EG=VSG/XX
      IF(EG.GT.1.0) GO TO 13001
      IF(EG.LT.0.0) GO TO 13002
      GO TO 13003
13001 EG=1.0
      GO TO 13003
13002 EG=0.0
C3003 WRITE (6,1500) EG
C500  FORMAT(T10,'EG      =',T17,F20.9)
C
13003 XLDEN=XLDEN
      AGDEN=AGDEN
      XMDEN=EG*AGDEN+(1-EG)*XLDEN
C     WRITE (6,1501) XMDEN
C501  FORMAT(T10,'XMDEN  =',T17,F20.9)

C
      X=0.429*VSL
      XX=0.357*VT
      XVSG=X+XX
C
      Y=XMDEN/ALIQV
      Y1=Y**0.08
      Y2=STLIQM/XLDEN
      Y3=Y2**0.6
      Y4=XLDEN-AGDEN
      Y5=Y4/STLIQM
      Y6=Y5*G
      Y7=Y6**0.5
      Y8=DIAM**0.48
      XVM=4.68*Y8*Y7*Y3*Y1
C
```

```
C     CONVERSION FACTOR=0.3023623
C
      XVM=XVM*0.9730692
C
      VMM=VM**1.12
C
C     ***************************************************************
C     *                                                             *
C     *                    SLUG CHARACTERS                          *
C     *                                                             *
C     ***************************************************************
C
      R=VSL**2
      R2=XLDEN*R
      R3=ALOG10(R2)
      R4=17.1*R3
      R5=R4-23.2
C
      XVSG1=VSG**2
      XVSG2=XVSG1*AGDEN
C
      R6=R2**1.7
      R7=0.00673*R6
C
C
C     CHURN CHARACTERS

      CC1=XLDEN-AGDEN
      CC2=AGDEN**2
      CC3=CC1/CC2
      CC4=STLIQM*G*CC3
      CC5=CC4**0.25
      CC6=3.1*CC5
C
C     CONVERSION FACTOR=0.216693
C
      CC6=CC6*0.216693
C
C
C
C
C
      IF(VSG.LT.XVSG) GO TO 400
      IF(EG.LT.0.52) GO TO 402
      GO TO 403
402   IF(VMM.GT.XVM) GO TO 500
      GO TO 403
400   IF(VT.LT.VTT) GO TO 500
      GO TO 403
C
C     ***************************************************************
```

```
C     *                                                    *
C     *              SLUG REGION                           *
C     *                                                    *
C     ******************************************************
C
403   IF(R2.GT.50) GO TO 404
      GO TO 405
404   IF(XVSG2.LT.R5)   GO TO 600
      GO TO 406
405   IF(XVSG2.LT.R7)   GO TO 600
      GO TO 406
C
C     ******************************************************
C     *                                                    *
C     *              SLUG REGION                           *
C     *                                                    *
C     ******************************************************
C
406   IF(VSG.GE.CC6) GO TO 800
      IF(R2.GT.50) GO TO 407
      GO TO 408
407   IF(XVSG2.GE.R5)   GO TO 700
      GO TO 800
408   IF(XVSG2.GE.R7)   GO TO 700
      GO TO 800
C
C*******************************************************
C*******************************************************
C                                                      *
C                                                      *
C     REGION ONE     BUBBLE FLOW                       *
C                                                      *
C                                                      *
C                                                      *
C*******************************************************
C*******************************************************
C
C
C
C
500   GS=XMDEN*(G/GC)
      GST=GS/144
C     WRITE (6,1502) GST
C502  FORMAT(T10,'GSTB   =',T17,F20.9)
C
C     CALCULATE FRICTION FACTOR
C
C     CALCULATE REYNOLDS NUMBER
      REN=((1488*XMDEN*VM*DIAM)/(ALIQV))
C     IF(REN.LE.0.0) REN=0.00001
C     WRITE (6,155) REN
```

```
C55   FORMAT(T10,'REN   =',T17,F20.10)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C     WRITE (6,156) RR
C56   FORMAT(T10,'RR    =',T17,F10.5)
C     IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 331
C     IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 332
C     IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 333
C     IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 334
C331  A1 = 0.26463610
C     B1 = -0.11017749
C     C1 = 0.01620292
C     D1 = -0.000789492
C     FF1B = B1*(ALOG10(REN))
C     FF1C = C1*((ALOG10(REN))**2)
C     FF1D = D1*((ALOG10(REN))**3)
C     FF = A1+FF1B+FF1C+FF1D
C     GO TO 337
C332  A2 = 0.24272863
C     B2 = -0.10086268
C     C2 = 0.01497258
C     D2 = -0.000735568
C     FF2B = B2*(ALOG10(REN))
C     FF2C = C2*((ALOG10(REN))**2)
C     FF2D = D2*((ALOG10(REN))**3)
C     FF = A2+FF2B+FF2C+FF2D
C     GO TO 337
C333  A3 = 0.23512834
C     B3 = -0.09713003
C     C3 = 0.01443852
C     D3 = -0.000710073
C     FF3B = B3*(ALOG10(REN))
C     FF3C = C3*((ALOG10(REN))**2)
C     FF3D = D3*((ALOG10(REN))**3)
C     FF = A3+FF3B+FF3C+FF3D
C     GO TO 337
C334  A4 = 1.62171267
C     B4 = -1.42794577
C     C4 = 0.51701972
C     D4 = -0.09404856
C     E4 = 0.008523510
C     F4 = -0.000306004
C     FF4B = B4*(ALOG10(REN))
C     FF4C = C4*((ALOG10(REN))**2)
C     FF4D = D4*((ALOG10(REN))**3)
C     FF4E = D4*((ALOG10(REN))**4)
C     FF4F = D4*((ALOG10(REN))**5)
C     FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
      ZZ1=RR**1.1098
      ZZ2=ZZ1/2.8257
```

```
      ZZ3=7.149/REN
      ZZ4=ZZ3**0.8981
      AZZ=ZZ2+ZZ4
C
      ZZ5=ALOG10(AZZ)
      ZZ6=5.0452*ZZ5
      ZZ7=ZZ6/REN
      ZZ8=RR/3.7065
      ZZ9=ZZ8-ZZ7
      ZZ10=ALOG10(ZZ9)
      ZZ11=4*ZZ10
      ZZ12=1/ZZ11
      FF=ZZ12**2
C
C
C37   WRITE (6,157) FF
C57   FORMAT(T10,'FF     =',T17,F10.5)
C
C     GF=(FF*XMDEN*(VM**2))/(2*GC*DIAM)
C337  PZ1=VM**2
      PZ1=VM**2
      PZ2=FF*XMDEN*PZ1
      P3=2.0*PZ2
      P4=GC*DIAM
      GF=P3/P4
C
      GFR=GF/144
C     WRITE (6,1503) GFR
C503  FORMAT(T10,'GFRB    =',T17,F20.9)
C
      GRAD=GST+GFR
C     WRITE (6,13013) GRAD
C3013 FORMAT(T10,'GRADB   =',T17,F20.9)
C
      GO TO 900
C
C
C     *****************************************************
C     *                                                   *
C     *                                                   *
C     *              REGION TWO    SLUG FLOW              *
C     *                                                   *
C     *                                                   *
C     *****************************************************
C
C
C
600   X1=XLDEN-AGDEN
      X2=X1*XLDEN
      X3=X2*G
      X4=DIAM**3
```

```
      X5=X3*X4
      X6=X5**0.5
      XNF=X6/ALIQV
C
C     CONVERSION FACTOR=1488
C
      XNF=XNF*1488

C
      IF(XNF.GT.250) GO TO 680
      IF(XNF.GE.18)  GO TO 681
      IF(XNF.LT.18)  GO TO 682
680   XM=10
      GO TO 690
681   XXM=XNF**(-0.35)
      XM=XXM*69
      GO TO 690
682   XM=25
C
690   X1=XLDEN-AGDEN
      X2=X1*G
      X3=DIAM**2
      X4=X2*X3
      EO=X4/STLIQM
C
C     CONVERSION FACTOR=453.5452
C
      EO=EO*453.5452

C
      Y1=-0.01*XNF
      Y2=Y1/0.345
      Y3=EXP(Y2)
      Y4=1-Y3
      Y5=3.37-EO
      Y6=Y5/XM
      Y7=EXP(Y6)
      Y8=1-Y7
      C2=0.345*Y4*Y8
C     WRITE (6,6555) C2
C555  FORMAT(T10,'C2    =',T17,F20.10)

C
      PP1=XLDEN-AGDEN
      PP2=PP1/XLDEN
      P3=G*DIAM*PP2
      P4=P3**0.5
      VTT=C2*P4
C
      C1=1.2
      R1=C1*VM
```

```
      R2=R1+VTT
      EG=VSG/R2
      IF(EG.GT.1.0) GO TO 13007
      IF(EG.LT.0.0) GO TO 13008
      GO TO 13009
13007 EG=1.0
      GO TO 13009
13008 EG=0.0
13009 HL=1.0-EG
C
      D1=XLDEN*HL
      D2=AGDEN*EG
      XMDEN=D1+D2
C     WRITE (6,6555) AGDEN
C555  FORMAT(T10,'AGDEN =',T17,F20.10)
C     WRITE(6,987)HL,EG
C87   FORMAT(3X,2(F9.2,2X))
      GS=XMDEN*(G/GC)
      GST=GS*1.0
      GST=GST/144
C     WRITE (6,6555) GST
C555  FORMAT(T10,'GSTS  =',T17,F20.10)
C     CALCULATE REYNOLDS NUMBER
      REN=((1488*XMDEN*VM*DIAM)/(ALIQV))
      IF(REN.LE.0.0) REN=0.00001
C     WRITE (6,655) REN
C55   FORMAT(T10,'REN   =',T17,F20.10)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C     WRITE (6,656) RR
C56   FORMAT(T10,'RR    =',T17,F10.5)
C     IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 631
C     IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 632
C     IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 633
C     IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 634
C631  A1 = 0.26463610
C     B1 = -0.11017749
C     C1 = 0.01620292
C     D1 = -0.000789492
C     FF1B = B1*(ALOG10(REN))
C     FF1C = C1*((ALOG10(REN))**2)
C     FF1D = D1*((ALOG10(REN))**3)
C     FF = A1+FF1B+FF1C+FF1D
C     GO TO 637
C632  A2 = 0.24272863
C     B2 = -0.10086268
C     C2 = 0.01497258
C     D2 = -0.000735568
C     FF2B = B2*(ALOG10(REN))
C     FF2C = C2*((ALOG10(REN))**2)
```

```
C       FF2D = D2*((ALOG10(REN))**3)
C       FF = A2+FF2B+FF2C+FF2D
C       GO TO 637
C633    A3 = 0.23512834
C       B3 = -0.09713003
C       C3 = 0.01443852
C       D3 = -0.000710073
C       FF3B = B3*(ALOG10(REN))
C       FF3C = C3*((ALOG10(REN))**2)
C       FF3D = D3*((ALOG10(REN))**3)
C       FF = A3+FF3B+FF3C+FF3D
C       GO TO 637
C634    A4 = 1.62171267
C       B4 = -1.42794577
C       C4 = 0.51701972
C       D4 = -0.09404856
C       E4 = 0.008523510
C       F4 = -0.000306004
C       FF4B = B4*(ALOG10(REN))
C       FF4C = C4*((ALOG10(REN))**2)
C       FF4D = D4*((ALOG10(REN))**3)
C       FF4E = D4*((ALOG10(REN))**4)
C       FF4F = D4*((ALOG10(REN))**5)
C       FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
        ZZ1=RR**1.1098
        ZZ2=ZZ1/2.8257
        ZZ3=7.149/REN
        ZZ4=ZZ3**0.8981
        AZZ=ZZ2+ZZ4
C
        ZZ5=ALOG10(AZZ)
        ZZ6=5.0452*ZZ5
        ZZ7=ZZ6/REN
        ZZ8=RR/3.7065
        ZZ9=ZZ8-ZZ7
        ZZ10=ALOG10(ZZ9)
        ZZ11=4*ZZ10
        ZZ12=1/ZZ11
        FF=ZZ12**2
C37     WRITE (6,1601) FF
C601    FORMAT(T10,'FF     =',T17,F10.5)
C
C637    PW1=VM**2
        PW1=VM**2
        PW2=FF*XLDEN*PW1
        P3=2.0*PW2
        P4=GC*DIAM
        GF=P3/P4
        GF=GF*HL
C
        GFY=GF*1.0
```

```
      GFR=GFY/144
C     WRITE(6,987)VSG,VM,VTT,C1,C2,EG,GST,GFR,EO,XM,XNF
C87   FORMAT(3X,11(F6.2,2X))
C     WRITE (6,1603) GFR
C603  FORMAT(T10,'GFRS   =',T17,F20.9)
C
      GRAD=GST+GFR
C     WRITE(6,987)GST,GFR
C87   FORMAT(3X,2(F9.2,2X))
C     WRITE (6,1604) GRAD
C604  FORMAT(T10,'GRADS =',T17,F10.5)
      GO TO 900
C
C     **************************************************
C     *                                                *
C     *                                                *
C     *             REGION THREE  CHURN FLOW           *
C     *                                                *
C     *                                                *
C     **************************************************
C
700   C1=1.0
      B1=C1*VM
      B2=B1+VTT
      EG=VSG/B2
      IF(EG.GT.1.0) GO TO 13004
      IF(EG.LT.0.0) GO TO 13005
      GO TO 13006
13004 EG=1.0
      GO TO 13006
13005 EG=0.0
C
13006 HL=1-EG
      C1=EG*AGDEN
      C2=HL*XLDEN
      XMDEN=C1+C2
      GS=XMDEN*(G/GC)
      GST=GS/144
C     WRITE (6,7555) GST
C555  FORMAT(T10,'GSTC  =',T17,F20.10)
C
C     CALCULATE REYNOLDS NUMBER
C
C
      REN=((1488*XMDEN*VM*DIAM)/(ALIQV))
      IF(REN.LE.0.0) REN=0.00001
C     WRITE (6,755) REN
C55   FORMAT(T10,'REN   =',T17,F20.10)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
```

```
C     WRITE (6,756) RR
C56   FORMAT(T10,'RR    =',T17,F10.5)
C     IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 731
C     IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 732
C     IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 733
C     IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 734
C731  A1 = 0.26463610
C     B1 = -0.11017749
C     C1 = 0.01620292
C     D1 = -0.000789492
C     FF1B = B1*(ALOG10(REN))
C     FF1C = C1*((ALOG10(REN))**2)
C     FF1D = D1*((ALOG10(REN))**3)
C     FF = A1+FF1B+FF1C+FF1D
C     GO TO 737
C732  A2 = 0.24272863
C     B2 = -0.10086268
C     C2 = 0.01497258
C     D2 = -0.000735568
C     FF2B = B2*(ALOG10(REN))
C     FF2C = C2*((ALOG10(REN))**2)
C     FF2D = D2*((ALOG10(REN))**3)
C     FF = A2+FF2B+FF2C+FF2D
C     GO TO 737
C733  A3 = 0.23512834
C     B3 = -0.09713003
C     C3 = 0.01443852
C     D3 = -0.000710073
C     FF3B = B3*(ALOG10(REN))
C     FF3C = C3*((ALOG10(REN))**2)
C     FF3D = D3*((ALOG10(REN))**3)
C     FF = A3+FF3B+FF3C+FF3D
C     GO TO 737
C734  A4 = 1.62171267
C     B4 = -1.42794577
C     C4 = 0.51701972
C     D4 = -0.09404856
C     E4 = 0.008523510
C     F4 = -0.000306004
C     FF4B = B4*(ALOG10(REN))
C     FF4C = C4*((ALOG10(REN))**2)
C     FF4D = D4*((ALOG10(REN))**3)
C     FF4E = D4*((ALOG10(REN))**4)
C     FF4F = D4*((ALOG10(REN))**5)
C     FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
      ZZ1=RR**1.1098
      ZZ2=ZZ1/2.8257
      ZZ3=7.149/REN
      ZZ4=ZZ3**0.8981
      AZZ=ZZ2+ZZ4
C
```

```
      ZZ5=ALOG10(AZZ)
      ZZ6=5.0452*ZZ5
      ZZ7=ZZ6/REN
      ZZ8=RR/3.7065
      ZZ9=ZZ8-ZZ7
      ZZ10=ALOG10(ZZ9)
      ZZ11=4*ZZ10
      ZZ12=1/ZZ11
      FF=ZZ12**2
C37   WRITE (6,1701) FF
C701  FORMAT(T10,'FF     =',T17,F10.5)
C
C737  PQ1=VM**2
      PQ1=VM**2
      PQ2=FF*XLDEN*PQ1
      P3=2.0*PQ2
      P4=GC*DIAM
      GF=P3/P4
      GF=GF*HL
C
      GFX=GF*1.0
      GFR=GFX/144
C     WRITE (6,1703) GFR
C703  FORMAT(T10,'GFRC   =',T17,F20.9)
C
      GRAD=GST+GFR
C     WRITE (6,1704) GRAD
C704  FORMAT(T10,'GRADC =',T17,F10.5)
      GO TO 900
C
C     **************************************************
C     *                                                *
C     *                                                *
C     *            REGION FOUR  ANNULAR FLOW            *
C     *                                                *
C     *                                                *
C     **************************************************
C
C     CALCULATE GAS VISCOSITY
C
C
C     CALCULATE THE MOLECULAR WT OF THE GAS
800   GMWT=SPGGAS*29
C     CALCULATE VISCOSITY OF THE GAS
C     XXX=3.5+986/(TAVG+460)+0.01*GMWT
      X1=TAVG+460
      X2=0.01*GMWT
      X3=986/X1
      XXX=3.5+X3+X2
C
      GAMMA=2.4-0.2*XXX
```

```
C     AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
C    *(209+19*GMWT+(TAVG+460))
      X1=0.02*GMWT
      X2=9.4+X1
      X3=TAVG+460
      X4=X3**1.5
      X5=X2*X4
      X6=TAVG+460
      X7=19*GMWT
      X8=209+X6+X7
      AKKK=X5/X8
C
C     AGASVI=AKKK*0.0001*EXP(XXX*((AGDEN*454/30.8**3)**GAMMA))
      X1=30.8**3
      X2=AGDEN*454
      X3=X2/X1
      X4=X3**GAMMA
      X5=XXX*X4
      X6=EXP(X5)
      AGASVI=AKKK*0.0001*X6
C     WRITE (6,4001) AGASVI
C001  FORMAT(T10,'AGASVI=',T17,F10.5)
C
      UG=AGASVI
      C1=AGDEN/XLDEN
      C2=C1**0.5
      C3=VSG*UG*C2
      VSGC=C3/STLIQM
C
C     CONVERSION FACTORS:0.000672 AND 0.002204852
C
      VSGC=VSGC*0.000672
      ZZZZ=1/0.002204852
      VSGC=VSGC*ZZZZ
C
      C4=VSGC*10000
      IF(C4.GT.4) GO TO 1801
      GO TO 1802
C
1801  D1=ALOG10(C4)
      D2=0.857*D1
      E=D2-0.20
      GO TO 1803
C
1802  D3=C4**2.86
      E=D3*0.0055
1803  IF(E.GT.1.0) GO TO 8765
      IF(E.LT.0.0) GO TO 8764
8765  E=1.0
      GO TO 8763
8764  E=0.0
```

```
C
8763  E1=VSG*AGDEN
      E2=E*VSL
      E3=E2*XLDEN
      E4=E1+E3
      E5=E*VSL
      E6=VSG+E5
      PC=E4/E6
      GST=PC
      GST=GST/144
C     WRITE (6,8177) GST
C177  FORMAT(T10,'GSTA  =',T17,F20.9)
C
C
C
      EGC1=E*VSL
      EGC2=VSG+EGC1
      EGC=VSG/EGC2
C
      X1=AGDEN*EGC
      X2=1-EGC
      X3=VSL*X2
      X4=X1+X3
      X=X1/X4
C
C
      X2=1-X
      X3=X2/X
      X4=X3**0.9
      X5=AGDEN/XLDEN
      X6=X5**0.5
      X7=ALIQV/UG
      X8=X7**0.1
      XX=X4*X6*X8
C
      X9=XX**0.8
      X10=1+X9
      EG=X10**0.378
      IF(EG.GT.1.0) GO TO 13010
      IF(EG.LT.0.0) GO TO 13011
      GO TO 13012
13010 EG=1.0
      GO TO 13012
13011 EG=0.0

C
13012 REN=((1488*XMDEN*VM*DIAM)/(ALIQV))
      F1=REN**0.25
      F2=1-EG
      F3=75*F2
      F4=1+F3
```

```
      F5=0.079*F4
      FC=F5/F1
C
      G1=VSG/EG
      G2=G1**2
      G3=G2*PC
      G4=G3*FC
      G5=2*G4
      G6=GC*DIAM
      DELPF=G5/G6
      GFR=DELPF
      GFR=GFR/144
C     WRITE (6,8178) GFR
C178  FORMAT(T10,'GFRA  =',T17,F20.9)
C
      GRAD=GFR+GST
C     WRITE (6,13014) GRAD
C3014 FORMAT(T10,'GRADA =',T17,F20.9)
C
C
900   DELPP=DELTAH*GRAD
C     WRITE(6,9080)DELPP,DELP
C080  FORMAT(3X,2(F8.2,2X))
      DXDX=ABS(DELP-DELPP)
      NITR=NITR+1
      IF(NITR.GT.50) GO TO 3333
      GO TO 3334
3333  DELPP=DELP
      GO TO 8878
3334  IF(DXDX.GT.0.01) GO TO 23456
C
C
C     WRITE (8,817) DELTAH
C17   FORMAT(T10,'DELTAH=',T17,F20.9)
C     CALCULATE TOTAL DEPTH
8878  DEPTH1=DEPTH1+DELTAH
      P2=P1+DELPP
C     WRITE(6,908)DEPTH1,P2
C08   FORMAT(3X,2(F9.2,2X))
C     CHECK IF TOTAL DEPTH IS REACHED
      IF(DEPTH1.GE.TOTDEP) GO TO 1831
      GO TO 1832
1831  DEPTH2=DEPTH1-TOTDEP
      DDD1=DEPTH2/DELTAH
      DDD2=DDD1*DELPP
      P2=P2-DDD2
      DEPTH1=DEPTH1-DEPTH2
C
C
1832  IF(IPROF.EQ.1) WRITE(14,908)DEPTH1,P2
908   FORMAT(3X,2(F9.2,2X))
```

```
C     WRITE(6,9088)DEPTH1,VSG,CC6,XVSG,XVSG2,R5,R2,R7
C088  FORMAT(3X,8(F8.2,2X))
      FGE=DEPTH1-TOTDEP
      IF(FGE.EQ.0.0) GO TO 1000
C
      IF(DEPTH1.GE.TOTDEP) GO TO 1000
C     ASSUME P1 EQUAL TO P2 AND DEPTH1 EQUAL TO DEPTH2 AND ITERATE
      P1=P2
      T1=T2
      GO TO 11
C1000 STOP    JUST FOR TEST
1000  BHFP=P2
      RETURN
      END
```

```
C
C     THIS IS THE ORIGINAL ORKIS PROGRAM
C
C     ORKISWISKY
      SUBROUTINE ORKIS (VS,RESTMP,SURTMP,P1,DEPTH1,OILRTE,WTRRTE,
     &DIMTB,API,GOR,DIMTSG,DIMTBG,SPGWTR,SPGGAS,STNOIL,STNWTR,BW,EE,
     &DELP,DELTAH,G,GC,T1,TOTDEP,DIMTB2,DEPTB2,BHFP,IPROF)
C
C     NITRM=20
C
      DEPTH1=0.
C     STEP : 1 CALCULATE SPECIFIC GRAVITY OF OIL
      SPGOIL=141.5/(131.5+API)
C     WRITE (6,101) SPGOIL
  101 FORMAT(T10,' SPGOIL =',T17,F10.5)
C     STEP : 2 CALCULATE GLR WOR WCUT TOTAL LIQUID AND FLUID GRADIENT
      GLR=GOR*(OILRTE/(OILRTE+WTRRTE))
C     WRITE (6,102) GLR
102   FORMAT(T10,' GLR =',T17,F10.5)
      WOR=WTRRTE/OILRTE
C     WRITE (6,103) WOR
103   FORMAT(T10,' WOR =',T17,F10.5)
      WCUT=WTRRTE/(OILRTE+WTRRTE)
      WTRCUT=WCUT
C     WRITE (6,104) WCUT
104   FORMAT(T10,' WCUT =',T17,F10.5)
      TOTLIQ=OILRTE+WTRRTE
C     WRITE (6,105) TOTLIQ
105   FORMAT(T10,' TOTLIQ =',T17,F10.1)
      APRXGD=.433*WCUT+SPGOIL*.433*(1.0-WCUT)
C     WRITE (6,106) APRXGD
106   FORMAT(T10,' APRXGD =',T17,F10.5)
C     STEP : 4 CALCULATE MASS ASSOCIATED WITH 1 STB OF LIQUID
      AMASS=((SPGOIL*350.0)*(1.0-WCUT))
      BMASS=SPGWTR*350.0*WCUT
      CMASS=0.0764*GLR*SPGGAS
      TM=AMASS+BMASS+CMASS
C     WRITE (6,108) TM
108   FORMAT(T10,' TM   =',T17,F10.5)
C     STEP : 5 CALCULATE MASS FLOW RATE
      W1=TM*TOTLIQ
C     WRITE (6,109) W1
109   FORMAT(T10,' W1   =',T17,F10.0)
C     STEP : 6 CALCULATE TEMPERATURE GRADIENT
      TEMGRD=(RESTMP-SURTMP)/TOTDEP
C     WRITE (6,110) TEMGRD
110   FORMAT(T10,' TEMGRD=',T17,F10.5)
C     WRITE (6,111) T1
C11   FORMAT(T10,' T1    =',T17,F10.5)
C     STEP : 7 CALCULATE AVERAGE TEMP AND AVERAGE PRESS
C1    DELDEP=DELP/APRXGD
```

```
11    NITR=0
      DELP=25
      GO TO 20038
20037 DELP=DELPP
C
C     NITR=0
C     NITR=NITR+1
C     IF(NITR.GT.NITRM) GO TO 50001
C
C     CALCULATE THE AREA OF FLOW
20038 IF(DIMTSG.EQ.0.0) GO TO 12
      AREA=(22/7)*((DIMTSG**2-DIMTBG**2)/4)
      GO TO 14
12    IF(DEPTH1.LE.DEPTB2) GO TO 938
      DIAM=DIMTB2
      GO TO 14001
938   DIAM=DIMTB
14001 AREA=22*DIAM**2/(4*7)
14    CONTINUE
C     WRITE (6,112) DELDEP
C12   FORMAT(T10,' DELDEP=',T17,F10.5)
      T2=T1+TEMGRD*DELTAH
C     WRITE (6,113) T2
113   FORMAT(T10,' T2    =',T17,F10.5)
13    TAVG=(T1+T2)/2
C     WRITE (6,114) TAVG
114   FORMAT(T10,' TAVG  =',T17,F10.5)
      P2=P1+DELP
C     WRITE (6,115) P2
115   FORMAT(T10,' P2    =',T17,F10.5)
C     WRITE (6,116) P1
116   FORMAT(T10,' P1    =',T17,F10.5)
      PAVG=(P1+P2)/2+14.7
C     WRITE (6,117) PAVG
117   FORMAT(T10,' PAVG  =',T17,F10.5)
C     STEP : 8 CALCULATE SOLUTION GAS AT AVGP P1 P2
19    X1=PAVG/18
      X2=(10**((.0125*(API))-(0.00091*TAVG)))
      X3=(((X1*X2))**(1/0.83))
      RSAVG=SPGGAS*X3
      IF(RSAVG.LE.GOR) GO TO 1111
      RSAVG=GOR
C111  WRITE (6,118) RSAVG
C18   FORMAT(T10,' RSAVG =',T17,F10.5)
C     P1
C111  X5=P1/18
C     X6=(10**((.0125*(API))-(0.00091*T1)))
C     X7=(((X5*X6))**(1/0.83))
C     RS1=SPGGAS*X7
C     IF(RS1.LE.GOR) GO TO 20
C     RS1=GOR
```

```
C     WRITE (6,119) RS1
C19   FORMAT(T10,' RS1   =',T17,F10.5)
C     P2
C0    X9=P2/18
C     X10=(10**((.0125*(API))-(0.00091*T2)))
C     X11=(((X9*X10))**(1/0.83))
C     RS2=SPGGAS*X11
C     IF(RS2.LE.GOR) GO TO 21
C     RS2=GOR
C     WRITE (6,120) RS2
C20   FORMAT(T10,' RS2   =',T17,F10.5)
C1    CONTINUE
C     STEP : 9 CALCULATE FORM. VOL. FACTOR AT PAVG,TAVG P1,T1 P2,T2
1111  FAVG=((RSAVG*((SPGGAS/SPGOIL)**0.5))+(1.25*TAVG))
      BOAVG=(0.972+((0.000147)*((FAVG**1.175))))
C     WRITE (6,121) BOAVG
C21   FORMAT(T10,' BOAVG =',T17,F10.5)
C     F1=((RS1*((SPGGAS/SPGOIL)**0.5))+(1.25*T1))
C     BO1=(0.972+((0.000147)*((F1**1.175))))
C     WRITE (6,122) BO1
C22   FORMAT(T10,' BO1   =',T17,F10.5)
C     F2=((RS2*((SPGGAS/SPGOIL)**0.5))+(1.25*T2))
C     BO2=(0.972+((0.000147)*((F2**1.175))))
C     WRITE (6,123) BO2
C23   FORMAT(T10,' BO2   =',T17,F10.5)
C     STEP : 10 CALCULATE THE DENSITY OF THE LIQUID PHASE
      G1=(SPGOIL*(62.4)+(RSAVG*SPGGAS*(0.0764))/(5.614))
      G2=((G1/BOAVG)*(1-WCUT))
      G3=((SPGWTR)*(62.4)*(WCUT))
      XLDEN=(G2+G3)
C     WRITE (6,124) XLDEN
C24   FORMAT(T10,'XLDEN  =',T17,F10.5)
C     AT P1
C     G4=(SPGOIL*(62.4)+(RS1*SPGGAS*(0.0764))/(5.614))
C     G5=((G4/BO1)*(1-WCUT))
C     G6=((SPGWTR)*(62.4)*(WCUT))
C     DEN1=(G5+G6)
C     WRITE (6,125) DEN1
CC5   FORMAT(T10,' DEN1  =',T17,F10.5)
C     AT P2
C     G7=(SPGOIL*(62.4)+(RS2*SPGGAS*(0.0764))/(5.614))
C     G8=((G7/BO2)*(1-WCUT))
C     G9=((SPGWTR)*(62.4)*(WCUT))
C     DEN2=(G8+G9)
C     WRITE (6,126) DEN2
C26   FORMAT(T10,' DEN2  =',T17,F10.5)
C     CALCULATE COMPRESSIBILITY FACTOR AT PAVG,TAVG P1,T1 P2,T2
      PPC=(709.604-58.718*(SPGGAS))
      TPC=(170.491+307.344*(SPGGAS))
      APR=PAVG/PPC
      ATR=(TAVG+460)/TPC
```

```
      PR1=(P1+14.7)/PPC
      TR1=(T1+460)/TPC
      PR2=(P2+14.7)/PPC
      TR2=(T2+460)/TPC
C     COEFFICIENTS
      A1=0.31506237
      A2=-1.04670990
      A3=-0.57832729
      A4=0.53530771
      A5=-0.61232032
      A6=-0.10488813
      A7=0.68157001
      A8=0.68446549
C     AT PAVG TAVG  ASSUME Z=1.0
      PR=APR
      TR=ATR
      AZ=1.0
      ZANTR=0
15    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
C     WRITE(6,70018)CZ,DEPTH1
C0018 FORMAT(3X,2(F9.4,2X))
C
C     ZANTR=ZANTR+1
C     IF(ZANTR.GT.20) GO TO 70010
C     GO TO 70011
C0010 WRITE (6,70012) ZANTR
C0012 FORMAT(T10,'ZANTR =',T17,F10.5)
C     STOP
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.001)  GO TO 30
      AZ=CZ
      GO TO 15
30    AVGZ=CZ
C     WRITE (6,127) AVGZ
C27   FORMAT(T10,' AVGZ  =',T17,F10.5)
C     AT P1 T1
C     PR=PR1
C     TR=TR1
C     AZ=1.0
C     Z1NTR=0
C25   CPR=(0.27*PR)/(AZ*TR)
C     AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
C     AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
C     AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
C     CZ=AK1+(AK2*AK3)
C     Z1NTR=Z1NTR+1
C     IF(Z1NTR.GT.20) GO TO 70013
```

```
C     GO TO 70015
C0013 WRITE (6,70014) Z1NTR
C0014 FORMAT(T10,'Z1NTR =',T17,F10.5)
C     STOP
C0015 ZDIF=ABS(CZ-AZ)
C     IF(ZDIF.LE.0.0001)  GO TO 35
C     AZ=CZ
C     GO TO 25
C5    Z1=CZ
C     WRITE (6,128) Z1
C28   FORMAT(T10,' Z1    =',T17,F10.5)
C     AT P2 T2
C     PR=PR2
C     TR=TR2
C     AZ=1.0
C     Z2NTR=0
C5    CPR=(0.27*PR)/(AZ*TR)
C     AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
C     AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
C     AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
C     CZ=AK1+(AK2*AK3)
C     Z2NTR=Z2NTR+1
C     IF(Z1NTR.GT.20) GO TO 70016
C     GO TO 70018
C0016 WRITE (6,70017) Z2NTR
C0017 FORMAT(T10,'Z2NTR =',T17,F10.5)
C     STOP
C0018 ZDIF=ABS(CZ-AZ)
C     IF(ZDIF.LE.0.001)  GO TO 40
C     AZ=CZ
C     GO TO 45
C0    Z2=CZ
C     WRITE (6,129) Z2
C29   FORMAT(T10,' Z2    =',T17,F10.5)
C     CALCULATE AVERAGE GAS DENSITY
      AGDEN=SPGGAS*0.0764*(PAVG/14.7)*(520/(TAVG+460))*(1/AVGZ)
C     WRITE (6,130) AGDEN
130   FORMAT(T10,' AGDEN =',T17,F10.5)
C     CALCULATE AVERAGE VISCOSITY OF OIL
      S=3.0324-0.02023*(API)
      Y=10**(S)
      X=Y*(T1**(-1.163))
      ADOILV=(10**X)-1
      A=10.715*((RSAVG+100)**(-0.515))
      B=5.44*((RSAVG+150)**(-0.338))
      AOILV=(A*(ADOILV**B))
C     WRITE (6,131) AOILV
131   FORMAT(T10,'AOILV =',T17,F10.5)
C     CALCULATE AVERAGE WATER VISCOSITY
      AWTRV=EXP(1.003-1.479E-2*TAVG+1.982E-5*(TAVG**(-2)))
C     WRITE (6,132) AWTRV
```

```
132    FORMAT(T10,'AWTRV =',T17,F10.5)
C      CALCULATE LIQUID MIXTURE VISCOSITY
       ALIQV=AOILV*(1-WCUT)+AWTRV*(WCUT)
C      WRITE (6,133) ALIQV
133    FORMAT(T10,'ALIQV =',T17,F10.5)
C      CALCULATE LIQUID MIXTURE SURFACE TENSION
       STLIQM=STNOIL*(1-WCUT)+STNWTR*(WCUT)
C      WRITE (6,134) STLIQM
134    FORMAT(T10,'STLIQM=',T17,F10.5)
C      CALCULATE LIQUID VISCOSITY NUMBER
       VLN=0.15726*ALIQV*(1/(XLDEN*STLIQM**3))**0.25
C      WRITE (6,135) VLN
135    FORMAT(T10,'VLN   =',T17,F10.5)
C      CALCULATE VISCOSITY NUMBER CORRECTION FACTOR CNL
       A = 0.01001681
       B = -0.01522753
       C = -0.03911264
       D = -0.02739780
       E = -0.007981444
       F = -0.000842104
       CNLB = B*(ALOG10(VLN))
       CNLC = C*((ALOG10(VLN))**2)
       CNLD = D*((ALOG10(VLN))**3)
       CNLE = E*((ALOG10(VLN))**4)
       CNLF = F*((ALOG10(VLN))**5)
       CNL = A+CNLB+CNLC+CNLD+CNLE+CNLF
C      WRITE (6,136) CNL
136    FORMAT(T10,'CNL   =',T17,F10.5)
C      CALCULATE SUPERFICIAL LIQUID VELOCITY
       BW=1.0
       AVGVSL=5.61*((OILRTE+WTRRTE)/(86400*AREA))
      **(BOAVG*(1-WCUT)+BW*(WCUT))
       VSL=AVGVSL
       IF(VSL.LE.0.0) GO TO 45001
       GO TO 45002
45001 VSL=0.1
C      WRITE (6,138) AVGVSL
138    FORMAT(T10,'AVGVSL=',T17,F10.5)
C      VSL1=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO1*(1-WCUT)+BW*(WCUT))
C5002 A1=OILRTE+WTRRTE
C      A2=86400*AREA
C      A3=5.61*A1
C      A4=A3/A2
C      A5=1-WCUT
C      A6=BO1*A5
C      A7=BW*WCUT
C      A8=A7+A6
C      VSL1=A4*A8
C      WRITE (6,139) VSL1
C39    FORMAT(T10,'VSL1  =',T17,F10.5)
C      VSL2=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO2*(1-WCUT)+BW*(WCUT))
```

```
C      B1=OILRTE+WTRRTE
C      B2=86400*AREA
C      B3=5.61*B1
C      B4=B3/B2
C      B5=1-WCUT
C      B6=BO1*B5
C      B7=BW*WCUT
C      B8=B7+B6
C      VSL2=A4*A8
C      WRITE (6,140) VSL2
C40    FORMAT(T10,'VSL2  =',T17,F10.5)
C      CALCULATE LIQUID VELOCITY NUMBER
45002 ANLV=1.938*VSL*((XLDEN/STLIQM)**0.25)
C      WRITE (6,141) ANLV
141    FORMAT(T10,'ANLV  =',T17,F10.5)
C      CALCULATE THE SUPERFICIAL GAS VELOCITY AT PAVG AND TAVG
       AVSG=((OILRTE)*(GOR-RSAVG)/(86400*AREA))*
      *(14.7/PAVG)*((TAVG+460)/520)*(AVGZ)
       VSG=AVSG
       IF(VSG.LE.0.0) GO TO 45003
       GO TO 45004
45003 VSG=0.1
C      WRITE (6,142) AVSG
142    FORMAT(T10,'AVSG  =',T17,F10.5)
C      CALCULATE THE SUPERFICIAL GAS VELOCITY AT P1 AND T1
C      VSG1=((OILRTE+WTRRTE)*(GLR-RS1*(1-WCUT))/(86400*AREA))*
C     *(14.7/P1)*((T1+460)/520)*(Z1)
C      A1=OILRTE+WTRRTE
C      A2=(1-WCUT)
C      A3=RS1*A2
C      A4=GLR-A3
C      A5=86400*AREA
C      A6=A4/A5
C      A7=A1*A6
C      B1=14.7/P1
C      B2=T1+460
C      B3=B2/520
C      B4=B1*B3*Z1
C      VSG1=A7*B4
C      WRITE (6,143) VSG1
C43    FORMAT(T10,'VSG1  =',T17,F10.5)
C      CALCULATE THE SUPERFICIAL GAS VELOCITY AT P2 AND T2
C      VSG2=((OILRTE+WTRRTE)*(GLR-RS2*(1-WCUT))/(86400*AREA))*
C     *(14.7/P2)*((T2+460)/520)*(Z2)
45004 VM=VSG+VSL
C      WRITE (6,144) VSG2
144    FORMAT(T10,'VSG2  =',T17,F10.5)
C      CALCULATE GAS VELOCITY NUMBER
       ANGV=1.938*AVSG*((XLDEN/STLIQM)**0.25)
C      WRITE (6,145) ANGV
145    FORMAT(T10,'ANGV  =',T17,F10.5)
```

```
C     CALCULATE QL AND QG
      QL=(6.49E-5)*((OILRTE*BOAVG)+(WTRRTE*BW))
C     WRITE (6,149) QL
C49   FORMAT(T10,'QL    =',T17,F10.5)
C     QG=(3.27E-7)*(AVGZ)*((OILRTE+WTRRTE)*(GLR-RSAVG)*(1-WCUT))*
C    *((TAVG+460)/PAVG)
      QG=(3.27E-7)*(AVGZ)*((OILRTE)*(GOR-RSAVG))*
     *((TAVG+460)/PAVG)
C     WRITE (6,150) QG
C50   FORMAT(T10,'QG    =',T17,F10.5)
      IF(QG.LE.0.0) GO TO 60
      GO TO 31000
60    QG=0.0
31000 QT=QL+QG
C     CALCULATE CORRECTED MASS FLOW RATE
      WL=4.05E-3*(OILRTE*SPGOIL+WTRRTE*SPGWTR)+8.85E-7*(OILRTE+WTRRTE)*
     *SPGGAS*(RSAVG)
C     WRITE (6,186) WL
C86   FORMAT(T10,'WL    =',T17,F10.5)
C     CALCULATE CORRECTED FREE GAS FLOW RATE
      WG=8.85E-7*(OILRTE)*(GOR-RSAVG)
      IF(WG.LE.0.0) GO TO 889
      GO TO 890
889   WG=0.0
C     WRITE (6,187) WG
C87   FORMAT(T10,'WG    =',T17,F10.5)
C     CALCULATE TOTAL FLOW RATE
890   WT=WL +WG
C     WRITE (6,185) WT
C85   FORMAT(T10,'WT    =',T17,F10.5)
C     THE CORRECTED DENSITIES
      XLDEN1=WL/QL
      IF(QG.LE.0.0) GO TO 70020
      GO TO 70021
70020 AGDEN=0.0
      GO TO 70022
C
70021 AGDEN=WG/QG
C     ***********************************************
C
C     VARIABLES TO TEST FLOW REGIONS
C
C     ***********************************************
70022 XN1=G*STLIQM
      XN1=XN1*0.002204852
      XN2=XLDEN1/XN1
      XN3=XN2**0.25
      XN4=XN3/AREA
      VGBAR=QG*XN4
      VT=QT/AREA
C
```

```
      AL1=VM**2
      AL2=AL1/DIAM
      AL3=0.2218*AL2
      ALB=1.071-AL3
C
      IF(ALB.LT.0.13) GO TO 20030
      GO TO 20031
20030 ALB=0.13
C
20031 IF(QG.LE.0.0) GO TO 500
      AL4=QL/QG
C0031 AL4=QL/QG
      AL5=VGBAR*AL4
      ALS=50+36*AL5
C
      AL6=AL5**0.75
      ALM=75+84*AL6
      QQ=QG/QT
C
C     *************************************************
C     *************************************************
C     *******                                **********
C     *******        DETERMINE FLOW REGION   **********
C     *******                                **********
C     *************************************************
C     *************************************************
C
      IF(QQ.LT.ALB) GO TO 500
C
      IF(QQ.GT.ALB.AND.VGBAR.LT.ALS) GO TO 600
C
      IF(VGBAR.LT.ALM.AND.VGBAR.GT.ALS) GO TO 700
C
      IF(VGBAR.GT.ALM) GO TO 800
C
C     WEISMAN AND KING FLOW PATTERN
C
C
C
C
C     FOR BUBBLE TO INTERMITTENT
C
C
C
C     X1=VSG**2
C     X2=G*DIAM
C     FRG=X1/X2
C
C     X3=VSG+VSL
C     X4=G*DIAM
C     X5=X4**(0.5)
```

```
C     FRT=X3/X5
C     X6=FRT**(1.56)
C     X7=0.2*X6
C
C
C     FOR INTERMITTENT TO ANNULAR
C
C
C
C     Y1=VSG/VSL
C     Y2=Y1**(5./8.)
C     Y3=25*Y2
C
C     Y4=VSG**2
C     Y5=G*DIAM
C     FRG=Y4/Y5
C
C     Y6=AGDEN**(0.5)
C     Y7=Y6*VSG
C     Y8=(XLDEN-AGDEN)
C     Y9=G*Y8*STLIQM
C     Y9=Y9*0.002204852
C     Y10=Y9**(0.25)
C     AKU=Y7/Y10
C
C     Y11=FRG*AKU
C
C     IF(FRG.LT.X7) GO TO 500
C     IF(Y11.LT.Y3) GO TO 600
C     GO TO 800
C
C
C     DUKLER FLOW PATTERN
C
C
C     X1I=XLDEN**(2.0)
C     X2I=X1I*G*(DIAM**2.0)
C     X3I=XLDEN-AGDEN
C     X4I=X3I*STLIQM
C     X4I=X4I*0.002204852
C     X5I=X2I/X4I
C     X6I=X5I**(0.25)
C
C     W1I=XLDEN-AGDEN
C     W2I=W1I*G*STLIQM*0.002204852
C     W3I=XLDEN**(2.0)
C     W4I=W2I/W3I
C     W5I=W4I**(0.25)
C     W6I=1.15*W5I
C     W7I=3.0*VSG
C     W8I=W7I-W6I
```

```
C
C     Y1I=XLDEN-AGDEN
C     Y2I=Y1I*G
C     Y3I=Y2I/XLDEN
C     Y4I=Y3I**(0.446)
C     Y5I=STLIQM/XLDEN
C     Y6I=Y5I**(0.089)
C     Y7I=DIAM**(0.429)
C     Y8I=Y6I*Y7I
C     Y9I=ALIQV/XLDEN
C     Y9I=Y9I**(.072)
C     Y10I=Y8I/Y9I
C     Y11I=Y4I*Y10I
C     Y12I=Y11I*4.0
C     Y12I=Y12I*4.61
C
C     HH=0.25
C     UGG=VSG/(1.0-HH)
C     U1I=((G*DIAM)**(0.5))
C     U2I=UGG/U1I
C     U3I=35.5*U2I
CC
C     U4I=((G*DIAM)**(0.5))
C     U5I=VM/U4I
C     U6I=U5I+0.22
C     U7I=40.6*U6I
C
C     V1I=AGDEN**(0.5)
C     V2I=V1I*VSG
C     V3I=XLDEN-AGDEN
C     V4I=STLIQM*G*V3I
C     V4I=V4I*0.002204852
C     V5I=V4I**(0.25)
C     V6I=V2I/V5I
C
C     IF(X6I.LE.4.36) GO TO 500
C     IF(VSL.GE.W8I) GO TO 600
C     IF(VM.GE.Y12I) GO TO 500
C     IF(U3I.GE.U7I) GO TO 700
C     IF(V6I.GT.3.1) GO TO 800
C
C
C
C     ********************************************************
C     ***********                                ***************
C     ***********        BUBBLE REGION           ***************
C     ***********                                ***************
C     ***    GRIFFITH CORRELATION FOR BUBBLE FLOW            ***
C     ***                                                    ***
C     ********************************************************
C
```

```
C
C     CALCULATE QL AND QG
500   QL=(6.49E-5)*((OILRTE*BOAVG)+(WTRRTE*BW))
C     WRITE (6,149) QL
C49   FORMAT(T10,'QL     =',T17,F10.5)
      QG=(3.27E-7)*(AVGZ)*(OILRTE)*(GOR-RSAVG)*
     *((TAVG+460)/PAVG)
      QT=QL+QG
C     WRITE (6,151) QT
C51   FORMAT(T10,'QT     =',T17,F10.5)
C     CALCULATE VOID FRACTION OF GAS
CC    HG=.5*(1+QT/(VS*AREA)-(((1+QT/(VS*AREA))**2-
CC   *4*QG/(VS*AREA))**.5))
CC    HG=.5*(1+QT/(AVSG*AREA)-(((1+QT/(AVSG*AREA))**2-
CC   *4*QG/(AVSG*AREA))**.5))
      VS=0.8
      XXA=(QT/(VS*AREA))
      XXB=(1+QT/(VS*AREA))**2
      XXC=((4*QG)/(VS*AREA))
      XXD=((XXB-XXC)**.5)
      XXE=1+XXA-XXD
      HG=0.5*XXE
C     WRITE (6,152) HG
C52   FORMAT(T10,'HG     =',T17,F10.5)
C     CALCULATE AVERAGE FLOWING DENSITY
      AFD=(1-HG)*XLDEN+HG*AGDEN
C     WRITE(6,888)XLDEN,AGDEN
C88   FORMAT(3X,2(F9.4,2X))
C     WRITE (6,153) AFD
C53   FORMAT(T10,'AFD    =',T17,F10.5)
C     CALCULATE LIQUID VELOCITY
      VL=QL/(AREA*(1-HG))
C     WRITE (6,154) VL
C54   FORMAT(T10,'VL     =',T17,F10.5)
C     CALCULATE REYNOLDS NUMBER
      REN=1488*XLDEN*DIAM*VL/(ALIQV)
C     WRITE (6,155) REN
C55   FORMAT(T10,'REN    =',T17,F20.10)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C     WRITE (6,156) RR
C56   FORMAT(T10,'RR     =',T17,F10.5)
C     IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 20032
C     IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 20033
C     IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 20034
C     IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 20035
C0032 A1 = 0.26463610
C     B1 = -0.11017749
C     C1 = 0.01620292
C     D1 = -0.000789492
```

```
C      FF1B = B1*(ALOG10(REN))
C      FF1C = C1*((ALOG10(REN))**2)
C      FF1D = D1*((ALOG10(REN))**3)
C      FF = A1+FF1B+FF1C+FF1D
C      GO TO 20036
C0033 A2 = 0.24272863
C      B2 = -0.10086268
C      C2 = 0.01497258
C      D2 = -0.000735568
C      FF2B = B2*(ALOG10(REN))
C      FF2C = C2*((ALOG10(REN))**2)
C      FF2D = D2*((ALOG10(REN))**3)
C      FF = A2+FF2B+FF2C+FF2D
C      GO TO 20036
C0034 A3 = 0.23512834
C      B3 = -0.09713003
C      C3 = 0.01443852
C      D3 = -0.000710073
C      FF3B = B3*(ALOG10(REN))
C      FF3C = C3*((ALOG10(REN))**2)
C      FF3D = D3*((ALOG10(REN))**3)
C      FF = A3+FF3B+FF3C+FF3D
C      GO TO 20036
C0035 A4 = 1.62171267
C      B4 = -1.42794577
C      C4 = 0.51701972
C      D4 = -0.09404856
C      E4 = 0.008523510
C      F4 = -0.000306004
C      FF4B = B4*(ALOG10(REN))
C      FF4C = C4*((ALOG10(REN))**2)
C      FF4D = D4*((ALOG10(REN))**3)
C      FF4E = D4*((ALOG10(REN))**4)
C      FF4F = D4*((ALOG10(REN))**5)
C      FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
C37    WRITE (6,157) FF
C57    FORMAT(T10,'FF    =',T17,F10.5)
C      CALCULATE TAU FRICTION
C0036 TAUF=FF*XLDEN*(VL**2)/(2*32.2*(DIAM))
      IF(REN.LE.2000) GO TO 16401
      GO TO 16402
16401 FF=64/REN
      GO TO 16405
16402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
```

```
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16406
      FF=FGI
16405 TAUF=FF*XLDEN*(VL**2)/(2*32.2*(DIAM))
C     WRITE (6,158) TAUF
C58   FORMAT(T10,'TAUF  =',T17,F10.5)
C     CALCULATE CHANGE IN DEPTH
C     DELTAH=144*(DELP)*(1-(WT*QG/(4637*(AREA**2)*(PAVG))))/(AFD+TAUF)
      AA1=AFD+TAUF
      AA2=AREA**2
      AA3=4637*AA2*PAVG
      AA4=WT*QG
      AA5=AA4/AA3
      AA6=1.0-AA5
      AA7=AA1/AA6
      GRAD=AA7/144
      DELPP=GRAD*DELTAH
      NITR=NITR+1
      IF(NITR.GT.21) GO TO 70000
      GO TO 70001
C0000 WRITE (6,158) NITR
158   FORMAT(T10,'NITRB =',T17,F10.5)
70000 GO TO 900
C
70001 DIFF=ABS(DELPP-DELP)
      IF(DIFF.GT.0.3) GO TO 20037
C     WRITE (6,157) DELPP
157   FORMAT(T10,'BUB   =',T17,F10.5)
      GO TO 900
C
C     *******************************************************
C     **********                                 ***********
C     **********                                 ***********
C     **********          SLUG REGION            ***********
C     **********                                 ***********
C     **********                                 ***********
C     *******************************************************
C     ASSUME A VALUE FOR VS
600   VSI1=G*DIAM
      VSI2=VSI1**0.5
      VSI=0.5*VSI2
      GO TO 20005
```

```
20004 VSI=VB
C     NITR=0
C     NITR=NITR+1
C     IF(NITR.GT.NITRM) GO TO 50001
C     CALCULATE NREB AND NREL
20005 ANREB=1488*XLDEN1*VSI*DIAM/ALIQV
C
      ANREL=1488*XLDEN1*VM*DIAM/ALIQV
C
C
C
C     DETERMINE FLOW REGION
C
C
C
      IF(ANREB.LE.3000) GO TO 20000
      IF(ANREB.GT.3000.AND.ANREB.LT.8000) GO TO 20001
      IF(ANREB.GE.8000) GO TO 20002
20000 VB1=G*DIAM
      VB1=VB1**0.5
      VB2=8.74E-6*ANREL
      VB3=0.546+VB2
      VB=VB3*VB1
      GO TO 20003
C
20001 EI1=G*DIAM
      EI1=EI1**0.5
      EI2=8.74E-6*ANREL
      EI3=0.251+EI2
      EI=EI3*EI1
C
      VB1=DIAM**0.5
      VB2=XLDEN1*VB1
      VB3=13.59*ALIQV
      VB4=VB3/VB2
      VB5=EI**2
      VB6=VB5+VB4
      VB7=VB6**0.5
      VB8=EI+VB7
      VB=0.5*VB8
      GO TO 20003
C
20002 VB1=G*DIAM
      VB2=VB1**0.5
      VB3=8.74E-6*ANREL
      VB4=0.35+VB3
      VB=VB4*VB2
      GO TO 20003
C
20003 VSB=ABS(VSI-VB)
C
```

```
      IF(VSB.GE.0.10000) GO TO 20004
C
C
C
C     XE=THE LIQUID DISTRIBUTION FACTOR
C
C
C
      IF(WCUT.GE.0.75) GO TO 20006
      GO TO 20007
C
20006 IF(VM.GE.10) GO TO 20008
      GO TO 20009
C
20008 XE1=ALOG10(DIAM)
      XE2=0.888*XE1
      XE3=ALOG10(VM)
      XE4=0.162*XE3
      XE5=DIAM**0.799
      XE6=ALOG10(ALIQV)
      XE7=0.045*XE6
      XE8=XE7/XE5
      XE=XE8-0.709-XE4-XE2
      GO TO 20010
C
20009 XE1=ALOG10(DIAM)
      XE2=0.428*XE1
      XE3=ALOG10(VM)
      XE4=0.232*XE3
      XE5=DIAM**1.38
      XE6=ALOG10(ALIQV)
      XE7=0.013*XE6
      XE8=XE7/XE5
      XE=XE8-0.681+XE4-XE2
      GO TO 20010
C
20007 IF(VM.GE.10) GO TO 20011
      GO TO 20012
C
20011 XX1=ALOG10(DIAM)
      XX2=0.63*XX1
      XX3=DIAM**1.571
      XX4=1+ALIQV
      XX5=ALOG10(XX4)
      XX6=0.01*XX5
      XX7=XX6/XX3
      XX8=XX7+0.397+XX2
      XX9=ALOG10(VM)
      XX10=-1.0*XX9
      XX=XX10*XX8
C
```

```
      XE1=ALOG10(DIAM)
      XE2=0.569*XE1
      XE3=DIAM**1.371
      XE4=1.0+ALIQV
      XE5=ALOG10(XE4)
      XE6=0.0274*XE5
      XE7=XE6/XE3
      XE=XE7+0.161+XE2+XX
      GO TO 20010
C
20012 XE1=ALOG10(DIAM)
      XE2=0.113*XE1
      XE3=ALOG10(VM)
      XE4=0.167*XE3
      XE5=DIAM**1.415
      XE6=1.0+ALIQV
      XE7=ALOG10(XE6)
      XE8=0.0127*XE7
      XE9=XE8/XE5
      XE=XE9-0.284+XE4+XE2
      GO TO 20010
C
20010 IF(VM.GE.10) GO TO 20013
      GO TO 20014
C
20013 CONTINUE
C
C     ASSUME A VALUE FOR THE TOTAL DENSITY (GAS+LIQUID)= XLDEN
C
      SDEN=AGDEN
C     NITR=0
20019 SS1=SDEN/XLDEN1
      SS2=1.0-SS1
      SS3=VB/(VM+VB)
      SS3=-1.0*SS3
      SS4=SS3*SS2
      IF(XE.LT.SS4) GO TO 20015
      GO TO 20016
20015 XE=SS4
C
C
C     CALCULATE THE TWO PHASE DENSITY=STDEN
C
C
20016 YW1=XLDEN*XE
      YW2=AGDEN*VSG
      YW3=VSL+VB
      YW4=XLDEN*YW3
      YW5=YW2+YW4
      YW6=VM+VB
      YW7=YW5/YW6
```

```
      STDEN=YW7+YW1
      DDIFF=ABS(STDEN-SDEN)
      IF(DDIFF.GT.0.01000) GO TO 20017
      GO TO 20018
20017 SDEN=STDEN
      GO TO 20019
20018 CONTINUE
C
C     NITR=NITR+1
C     IF(NITR.GT.NITRM) GO TO 50001
C
      TPDEN=STDEN
      GO TO 20020
C
20014 XXX=-0.065*VM
      IF(XE.LT.XXX) GO TO 20021
      GO TO 20022
20021 XE=XXX
C
20022 YW1=XLDEN1*XE
      YW2=AGDEN*VSG
      YW3=VSL+VB
      YW4=XLDEN1*YW3
      YW5=YW2+YW4
      YW6=VM+VB
      YW7=YW5/YW6
      TPDEN=YW7+YW1
C     WRITE (6,90001) TPDEN
C0001 FORMAT(T10,'SLUGD  =',T17,F10.5)
      GO TO 20020
C
20020 CONTINUE
C     **********************************************************
C
C     CALCULATE FRICTION FACTOR
C
C     **********************************************************
C     CALCULATE REYNOLDS NUMBER
      REN=1488*XLDEN*DIAM*VM/(ALIQV)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C
C     IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 20023
C     IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 20024
C     IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 20025
C     IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 20026
C0023 A1 = 0.26463610
C     B1 = -0.11017749
C     C1 = 0.01620292
C     D1 = -0.000789492
```

```
C     FF1B = B1*(ALOG10(REN))
C     FF1C = C1*((ALOG10(REN))**2)
C     FF1D = D1*((ALOG10(REN))**3)
C     FF = A1+FF1B+FF1C+FF1D
C     GO TO 20027
C0024 A2 = 0.24272863
C     B2 = -0.10086268
C     C2 = 0.01497258
C     D2 = -0.000735568
C     FF2B = B2*(ALOG10(REN))
C     FF2C = C2*((ALOG10(REN))**2)
C     FF2D = D2*((ALOG10(REN))**3)
C     FF = A2+FF2B+FF2C+FF2D
C     GO TO 20027
C0025 A3 = 0.23512834
C     B3 = -0.09713003
C     C3 = 0.01443852
C     D3 = -0.000710073
C     FF3B = B3*(ALOG10(REN))
C     FF3C = C3*((ALOG10(REN))**2)
C     FF3D = D3*((ALOG10(REN))**3)
C     FF = A3+FF3B+FF3C+FF3D
C     GO TO 20027
C0026 A4 = 1.62171267
C     B4 = -1.42794577
C     C4 = 0.51701972
C     D4 = -0.09404856
C     E4 = 0.008523510
C     F4 = -0.000306004
C     FF4B = B4*(ALOG10(REN))
C     FF4C = C4*((ALOG10(REN))**2)
C     FF4D = D4*((ALOG10(REN))**3)
C     FF4E = D4*((ALOG10(REN))**4)
C     FF4F = D4*((ALOG10(REN))**5)
C     FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
C
C0027 CONTINUE
      IF(REN.LE.2000) GO TO 17401
      GO TO 17402
17401 FF=64/REN
      GO TO 17405
17402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

17406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
```

```
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 17405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 17406
      FF=FGI
17405 VK1=VSL+VB
      VK2=VM+VB
      VK3=VK1/VK2
      VK4=VK3+XE
      VK5=FF*XLDEN1
      VK6=VM**2
      VK7=VK5*VK6
      VK8=2*GC*DIAM
      VK9=VK7/VK8
      FGRAD=VK9*VK4
C
C     ***************************************************
C
C     TOTAL GRADIENT =TGRAD
C
C     ***************************************************
C
      TGRAD=TPDEN+FGRAD
      AA1=TGRAD
      AA2=AREA**2
      AA3=4637*AA2*PAVG
      AA4=WT*QG
      AA5=AA4/AA3
      AA6=1.0-AA5
      AA7=AA1/AA6
      GRAD=AA7/144
      DELPP=GRAD*DELTAH
      NITR=NITR+1
      IF(NITR.GT.21) GO TO 70002
      GO TO 70003
C0002 WRITE (6,70004) NITR
70004 FORMAT(T10,'NITRS =',T17,F10.5)
70002 GO TO 900
70003 DIFF=ABS(DELPP-DELP)
      IF(DIFF.GT.0.3) GO TO 20037
C     WRITE (6,60001) DELPP
60001 FORMAT(T10,'SLUG  =',T17,F10.5)
      GO TO 900
C     ***************************************************
C     ***************************************************
C     ***********                             ***********
```

```
C     ***********     REGION THREE          ***********
C     ***********    TRANSITION FLOW        ***********
C     ***********                           ***********
C     *************************************************
C     *************************************************
C
C     *************************************************
C     ******                                  *********
C     ****** TRANSITION REGION : SLUG FLOW    *********
C     ******                                  *********
C     *************************************************
C
C     ASSUME A VALUE FOR VS
700   VSI1=G*DIAM
      VSI2=VSI1**0.5
      VSI=0.5*VSI2
      GO TO 20105
20104 VSI=VB
C     CALCULATE NREB AND NREL
20105 ANREB=1488*XLDEN1*VSI*DIAM/ALIQV
C
      ANREL=1488*XLDEN1*VM*DIAM/ALIQV
C
C
C
C     DETERMINE FLOW REGION
C
C
C
      IF(ANREB.LE.3000) GO TO 20100
      IF(ANREB.GT.3000.AND.ANREB.LT.8000) GO TO 20101
      IF(ANREB.GE.8000) GO TO 20102
20100 VB1=G*DIAM
      VB1=VB1**0.5
      VB2=8.74E-6*ANREL
      VB3=0.546+VB2
      VB=VB3*VB1
      GO TO 20103
C
20101 EI1=G*DIAM
      EI1=EI1**0.5
      EI2=8.74E-6*ANREL
      EI3=0.251+EI2
      EI=EI3*EI1
C
      VB1=DIAM**0.5
      VB2=XLDEN1*VB1
      VB3=13.59*ALIQV
      VB4=VB3/VB2
      VB5=EI**2
      VB6=VB5+VB4
```

```
      VB7=VB6**0.5
      VB8=EI+VB7
      VB=0.5*VB8
      GO TO 20103
C
20102 VB1=G*DIAM
      VB2=VB1**0.5
      VB3=8.74E-6*ANREL
      VB4=0.35+VB3
      VB=VB4*VB2
      GO TO 20103
C
20103 VSB=ABS(VSI-VB)
C
      IF(VSB.GE.0.10000) GO TO 20104
C
C
C
C     XE=THE LIQUID DISTRIBUTION FACTOR
C
C
C
      IF(WCUT.GE.0.75) GO TO 20106
      GO TO 20107
C
20106 IF(VM.GE.10) GO TO 20108
      GO TO 20109
C
20108 XE1=ALOG10(DIAM)
      XE2=0.888*XE1
      XE3=ALOG10(VM)
      XE4=0.162*XE3
      XE5=DIAM**0.799
      XE6=ALOG10(ALIQV)
      XE7=0.045*XE6
      XE8=XE7/XE5
      XE=XE8-0.709-XE4-XE2
      GO TO 20110
C
20109 XE1=ALOG10(DIAM)
      XE2=0.428*XE1
      XE3=ALOG10(VM)
      XE4=0.232*XE3
      XE5=DIAM**1.38
      XE6=ALOG10(ALIQV)
      XE7=0.013*XE6
      XE8=XE7/XE5
      XE=XE8-0.681+XE4-XE2
      GO TO 20110
C
20107 IF(VM.GE.10) GO TO 20111
```

```
      GO TO 20112
C
20111 XX1=ALOG10(DIAM)
      XX2=0.63*XX1
      XX3=DIAM**1.571
      XX4=1+ALIQV
      XX5=ALOG10(XX4)
      XX6=0.01*XX5
      XX7=XX6/XX3
      XX8=XX7+0.397+XX2
      XX9=ALOG10(VM)
      XX10=-1.0*XX9
      XX=XX10*XX8
C
      XE1=ALOG10(DIAM)
      XE2=0.569*XE1
      XE3=DIAM**1.371
      XE4=1.0+ALIQV
      XE5=ALOG10(XE4)
      XE6=0.0274*XE5
      XE7=XE6/XE3
      XE=XE7+0.161+XE2+XX
      GO TO 20110
C
20112 XE1=ALOG10(DIAM)
      XE2=0.113*XE1
      XE3=ALOG10(VM)
      XE4=0.167*XE3
      XE5=DIAM**1.415
      XE6=1.0+ALIQV
      XE7=ALOG10(XE6)
      XE8=0.0127*XE7
      XE9=XE8/XE5
      XE=XE9-0.284+XE4+XE2
      GO TO 20110
C
20110 IF(VM.GE.10) GO TO 20113
      GO TO 20114
C
20113 CONTINUE
C
C     ASSUME A VALUE FOR THE TOTAL DENSITY (GAS+LIQUID)= XLDEN
C
      SDEN=AGDEN
20119 SS1=SDEN/XLDEN1
      SS2=1.0-SS1
      SS3=VB/(VM+VB)
      SS3=-1.0*SS3
      SS4=SS3*SS2
      IF(XE.LT.SS4) GO TO 20115
      GO TO 20116
```

```
20115 XE=SS4
C
C
C     CALCULATE THE TWO PHASE DENSITY=STDEN
C
C
20116 YW1=XLDEN1*XE
      YW2=AGDEN*VSG
      YW3=VSL+VB
      YW4=XLDEN1*YW3
      YW5=YW2+YW4
      YW6=VM+VB
      YW7=YW5/YW6
      STDEN=YW7+YW1
      DDIFF=ABS(STDEN-SDEN)
      IF(DDIFF.GT.0.01000) GO TO 20117
      GO TO 20118
20117 SDEN=STDEN
      GO TO 20119
20118 CONTINUE
      TPDEN=STDEN
      GO TO 20120
C
20114 XXX=-0.065*VM
      IF(XE.LT.XXX) GO TO 20121
      GO TO 20122
20121 XE=XXX
C
20122 YW1=XLDEN1*XE
      YW2=AGDEN*VSG
      YW3=VSL+VB
      YW4=XLDEN1*YW3
      YW5=YW2+YW4
      YW6=VM+VB
      YW7=YW5/YW6
      TPDENS=YW7+YW1
      GO TO 20120
C
20120 CONTINUE
C     ***********************************************************
C
C     CALCULATE FRICTION FACTOR
C
C     ***********************************************************
C     CALCULATE REYNOLDS NUMBER
      REN=1488*XLDEN1*DIAM*VM/(ALIQV)
C     CALCULATE FRICTION FACTOR
      EE=.00015
      RR=EE/DIAM
C
C     IF(RR.GE.0.0003000.AND.RR.LT.000500) GO TO 20123
```

```
C     IF(RR.GE.0.000500.AND.RR.LT.000700) GO TO 20124
C     IF(RR.GE.0.000700.AND.RR.LT.000900) GO TO 20125
C     IF(RR.GE.0.000900.AND.RR.LT.00100) GO TO 20126
C0123 A1 = 0.26463610
C     B1 = -0.11017749
C     C1 = 0.01620292
C     D1 = -0.000789492
C     FF1B = B1*(ALOG10(REN))
C     FF1C = C1*((ALOG10(REN))**2)
C     FF1D = D1*((ALOG10(REN))**3)
C     FF = A1+FF1B+FF1C+FF1D
C     GO TO 20127
C0124 A2 = 0.24272863
C     B2 = -0.10086268
C     C2 = 0.01497258
C     D2 = -0.000735568
C     FF2B = B2*(ALOG10(REN))
C     FF2C = C2*((ALOG10(REN))**2)
C     FF2D = D2*((ALOG10(REN))**3)
C     FF = A2+FF2B+FF2C+FF2D
C     GO TO 20127
C0125 A3 = 0.23512834
C     B3 = -0.09713003
C     C3 = 0.01443852
C     D3 = -0.000710073
C     FF3B = B3*(ALOG10(REN))
C     FF3C = C3*((ALOG10(REN))**2)
C     FF3D = D3*((ALOG10(REN))**3)
C     FF = A3+FF3B+FF3C+FF3D
C     GO TO 20127
C0126 A4 = 1.62171267
C     B4 = -1.42794577
C     C4 = 0.51701972
C     D4 = -0.09404856
C     E4 = 0.008523510
C     F4 = -0.000306004
C     FF4B = B4*(ALOG10(REN))
C     FF4C = C4*((ALOG10(REN))**2)
C     FF4D = D4*((ALOG10(REN))**3)
C     FF4E = D4*((ALOG10(REN))**4)
C     FF4F = D4*((ALOG10(REN))**5)
C     FF = A4+FF4B+FF4C+FF4D+FF4E+FF4F
C
C0127 CONTINUE
      IF(REN.LE.2000) GO TO 18401
      GO TO 18402
18401 FF=64/REN
      GO TO 18405
18402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
```

```
      FGI=0.0056+FGI
18406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 18405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 18406
      FF=FGI
18405 VK1=VSL+VB
      VK2=VM+VB
      VK3=VK1/VK2
      VK4=VK3+XE
      VK5=FF*XLDEN
      VK6=VM**2
      VK7=VK5*VK6
      VK8=2*GC*DIAM
      VK9=VK7/VK8
      FGRADS=VK9*VK4
C
C     **********************************************
C     ******                               *********
C     ****** TRASITION REGION : MIST FLOW  *********
C     ******                               *********
C     **********************************************
      S=0.0
      VS=0.0
      HL=((1/(1+(VSG/VSL))))
      IF(HL.GT.1.0) GO TO 20139
      IF(HL.LT.0.0) GO TO 20140
      GO TO 20141
20139 HL=1.0
      GO TO 20141
20140 HL=0.0
C2    WRITE (6,801) HL
C01   FORMAT(T10,'HL MIST=',T17,F20.9)
C     CALCULATE THE MOLECULAR WT OF THE GAS
20141 GMWT=SPGGAS*29
C     WRITE (8,802) GMWT
C02   FORMAT(T10,'GMWT  =',T17,F10.5)
C     CALCULATE VISCOSITY OF THE GAS
      XXX=3.5+986/(TAVG+460)+0.01*GMWT
      GAMMA=2.4-0.2*XXX
```

```
      AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
     *(209+19*GMWT+(TAVG+460))
C
C     THIS GAS DENSITY IS RECOMMENDED BY ORKISWISKY
C
      AA1=G*STLIQM
      AA1=AA1*0.002204852
      AA2=XLDEN/AA1
      AA3=AA2**(-0.25)
      AA4=ALM*AA3
      AADEN=AREA*AA4
C
      AGASVI=AKKK*0.0001*EXP(XXX*((AADEN*454/30.8**3)**GAMMA))
C     WRITE (8,803) AGASVI
C03   FORMAT(T10,'AGASVI=',T17,F10.5)
      REN=((1488*AADEN*VSG*DIAM)/(AGASVI))
C     WRITE (6,804) REN
C04   FORMAT(T10,'RENM  =',T17,F20.9)
      RAW=(AADEN/XLDEN)
C     WRITE (8,805) RAW
C05   FORMAT(T10,'RAW   =',T17,F10.5)
      EEE=(0.05*DIAM)
C     WRITE (8,806) EEE
C06   FORMAT(T10,'EEE   =',T17,F10.5)
      IF(EE.GT.EEE) GO TO 20153
C     FIND FF FROM MOODY DIAGRAM
C     FIND FF
C     CALCULATE FRICTION FACTOR
      EE=.00015
C     RR=EE*12/DIAM
      RR=EE/DIAM
C     WRITE (8,807) RR
C07   FORMAT(T10,'RR    =',T17,F10.5)
C     IF(REN.GE.1000000) GO TO 20142
C     IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 20143
C     IF(REN.GT.10000.AND.REN.LT.100000) GO TO 20144
C     IF(REN.GT.3600.AND.REN.LT.10000) GO TO 20145
C
C0142 F1A=0.005
C     GO TO 20146
C0143 F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
C     GO TO 20146
C0144 F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
C     GO TO 20146
C0145 F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
C0146 CONTINUE
C
C
C
C     IF(REN.GE.1000000) GO TO 20147
C     IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 20148
```

```
C     IF(REN.GT.10000.AND.REN.LT.100000) GO TO 20149
C     IF(REN.GT.3600.AND.REN.LT.10000) GO TO 20150
C0147 F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
C     GO TO 20151
C0148 F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
C     GO TO 20151
C0149 F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
C     GO TO 20151
C0150 F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
C0151 FF=F1B+(F1A-F1B)*((RR-0.0001)/0.001)
C     WRITE (8,808) FF
C08   FORMAT(T10,'FF    =',T17,F10.5)
      IF(REN.LE.2000) GO TO 19401
      GO TO 19402
19401 FF=64/REN
      GO TO 19405
19402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

19406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 19405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 19406
      FF=FGI
19405 FF1=FF
C     WRITE (8,809) FF1
C09   FORMAT(T10,'FF1   =',T17,F10.5)
      FW=FF1
C     WRITE (8,810) FW
C10   FORMAT(T10,'FW    =',T17,F10.5)
      GO TO 20152
20153 SSSS=(0.027*EE/DIAM)
C     WRITE (8,811) SSSS
C11   FORMAT(T10,'SSSS  =',T17,F10.5)
      FF1=((1/((4*(ALOG10(SSSS)))**2))+((0.067*((EE/DIAM)**1.73))))
C     WRITE (8,812) FF1
C12   FORMAT(T10,'FF1   =',T17,F10.5)
C     VSG=((VSG*((DIAM)**2)/(DIAM-EE)))
      FW=FF1
```

```
20152 AND=120.872*DIAM*((XLDEN/STLIQM)**0.5)
      GFR=(0.5*FW*RAW*((ANGV**2)/(AND)))
      IF(GFR.LT.0.0) GO TO 20154
      GO TO 20155
20154 GFR=0.0
C     WRITE (8,813) GFR
C13   FORMAT(T10,'GFRM  =',T17,F10.5)
20155 FGRADM=GFR
      GST=(HL+(1-HL)*(AADEN/XLDEN))
      TPDENM=GST
C     WRITE (8,814) GST
C14   FORMAT(T10,'GSTM  =',T17,F10.5)
C
C     ***************************************************
C     ***************************************************
C     ***                                            ****
C     ** CALCULATE THE AVERAGE DENSITY AND FRICTION FACTOR **
C     ** BETWEEN THE SLUG FLOW AND THE MIST FLOW          **
C     ***                                             ***
C     ***************************************************
C     ***************************************************
      Y01=ALM-VGBAR
      Y02=ALM-ALS
      Y03=Y01/Y02
      DSLUG=Y03*TPDENS
      Y04=VGBAR-ALS
      Y05=ALM-ALS
      Y06=Y04/Y05
      DMIST=Y06*TPDENM
      DEN=DSLUG+DMIST
C
      FSLUD=Y03*FGRADS
      FMIST=Y06*FGRADM
      FGRA=FSLUG+FMIST
C
C
      TGRAD=DEN+FGRA
      AA1=TGRAD
      AA2=AREA**2
      AA3=4637*AA2*PAVG
      AA4=WT*QG
      AA5=AA4/AA3
      AA6=1.0-AA5
      AA7=AA1/AA6
      GRAD=AA7/144
      DELPP=GRAD*DELTAH
      DIFF=ABS(DELPP-DELP)
      IF(DIFF.GT.0.3) GO TO 20037
C     WRITE (6,814) DELPP
814   FORMAT(T10,'GRADT =',T17,F10.5)
      GO TO 900
```

```
C
C
C     ************************************************
C     ************************************************
C     ***********                         ***********
C     ***********     REGION FOUR         ***********
C     ***********      MIST FLOW          ***********
C     *********** DUNS AND ROS CORRELATION ***********
C     ************************************************
C     ************************************************
800   S=0.0
      VS=0.0
      HL=((1/(1+(VSG/VSL))))
      IF(HL.GT.1.0) GO TO 20039
      IF(HL.LT.0.0) GO TO 20040
      GO TO 20041
20039 HL=1.0
      GO TO 20041
20040 HL=0.0
C2    WRITE (6,801) HL
C01   FORMAT(T10,'HL MIST=',T17,F20.9)
C     CALCULATE THE MOLECULAR WT OF THE GAS
20041 GMWT=SPGGAS*29
C     WRITE (8,802) GMWT
C02   FORMAT(T10,'GMWT  =',T17,F10.5)
C     CALCULATE VISCOSITY OF THE GAS
      XXX=3.5+986/(TAVG+460)+0.01*GMWT
      GAMMA=2.4-0.2*XXX
      AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
     *(209+19*GMWT+(TAVG+460))
C
C     THIS GAS DENSITY IS RECOMMENDED BY ORKISWISKY
C
      AA1=G*STLIQM
      AA1=AA1*0.002204852
      AA2=XLDEN/AA1
      AA3=AA2**(-0.25)
      AA4=ALM*AA3
      AADEN=AREA*AA4
C
      AGASVI=AKKK*0.0001*EXP(XXX*((AADEN*454/30.8**3)**GAMMA))
C     WRITE (8,803) AGASVI
C03   FORMAT(T10,'AGASVI=',T17,F10.5)
      REN=((1488*AADEN*VSG*DIAM)/(AGASVI))
C     WRITE (6,804) REN
C04   FORMAT(T10,'RENM  =',T17,F20.9)
      RAW=(AADEN/XLDEN)
C     WRITE (8,805) RAW
C05   FORMAT(T10,'RAW   =',T17,F10.5)
      EEE=(0.05*DIAM)
C     WRITE (8,806) EEE
```

```
C06   FORMAT(T10,'EEE   =',T17,F10.5)
      IF(EE.GT.EEE) GO TO 20053
C     FIND FF FROM MOODY DIAGRAM
C     FIND FF
C     CALCULATE FRICTION FACTOR
      EE=.00015
C     RR=EE*12/DIAM
      RR=EE/DIAM
C     WRITE (8,807) RR
C07   FORMAT(T10,'RR    =',T17,F10.5)
C     IF(REN.GE.1000000) GO TO 20042
C     IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 20043
C     IF(REN.GT.10000.AND.REN.LT.100000) GO TO 20044
C     IF(REN.GT.3600.AND.REN.LT.10000) GO TO 20045
C
C0042 F1A=0.005
C     GO TO 20046
C0043 F1A=0.005+(-0.00073)*(ALOG10(REN)-6)
C     GO TO 20046
C0044 F1A=0.00573+(-0.00252)*(ALOG10(REN)-5)
C     GO TO 20046
C0045 F1A=0.00825+(-0.02675)*(ALOG10(REN)-4)
C0046 CONTINUE
C
C
C
C     IF(REN.GE.1000000) GO TO 20047
C     IF(REN.GT.100000.AND.REN.LT.1000000) GO TO 20048
C     IF(REN.GT.10000.AND.REN.LT.100000) GO TO 20049
C     IF(REN.GT.3600.AND.REN.LT.10000) GO TO 20050
C0047 F1B=0.00305+(-0.00053)*(ALOG10(REN)-7)
C     GO TO 20051
C0048 F1B=0.00358+(-0.00130)*(ALOG10(REN)-6)
C     GO TO 20051
C0049 F1B=0.00488+(-0.00268)*(ALOG10(REN)-5)
C     GO TO 20051
C0050 F1B=0.00756+(-0.01000)*(ALOG10(REN)-4)
C0051 FF=F1B+(F1A-F1B)*((RR-0.0001)/0.001)
C     WRITE (8,808) FF
C08   FORMAT(T10,'FF    =',T17,F10.5)
      IF(REN.LE.2000) GO TO 20401
      GO TO 20402
20401 FF=64/REN
      GO TO 20405
20402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

20406 B11=FGI**0.5
      B12=B11*REN
```

```
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 20405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 20406
      FF=FGI
20405 FF1=FF
C     WRITE (8,809) FF1
C09   FORMAT(T10,'FF1   =',T17,F10.5)
      FW=FF1
C     WRITE (8,810) FW
C10   FORMAT(T10,'FW    =',T17,F10.5)
      GO TO 20052
20053 SSSS=(0.027*EE/DIAM)
C     WRITE (8,811) SSSS
C11   FORMAT(T10,'SSSS  =',T17,F10.5)
      FF1=((1/((4*(ALOG10(SSSS)))**2))+((0.067*((EE/DIAM)**1.73)))
C     WRITE (8,812) FF1
C12   FORMAT(T10,'FF1   =',T17,F10.5)
C     VSG=((VSG*((DIAM)**2)/(DIAM-EE)))
      FW=FF1
20052 AND=120.872*DIAM*((XLDEN/STLIQM)**0.5)
      GFR=(0.5*FW*RAW*((ANGV**2)/(AND)))
      IF(GFR.LT.0.0) GO TO 20054
      GO TO 20055
20054 GFR=0.0
C     WRITE (8,813) GFR
C13   FORMAT(T10,'GFRM  =',T17,F10.5)
20055 GST=(HL+(1-HL)*(AADEN/XLDEN))
C     WRITE (8,814) GST
C14   FORMAT(T10,'GSTM  =',T17,F10.5)
C     GTOT=((GST+GFR)/(1-((XLDEN*VSL)+((AADEN*VSG)*(VSG/PAVG))))
      Y1=GFR+GST
      Y2=AADEN*VSG
      Y3=XLDEN*VSL
      Y4=Y2+Y3
      Y5A=(PAVG*144*32.174)
      Y5=VSG/Y5A
      Y6=Y4*Y5
      Y7=1-Y6
      GTOT=Y1/Y7
C     WRITE (8,815) GTOT
C15   FORMAT(T10,'GTOT  =',T17,F10.5)
      DELPH=((GTOT*XLDEN)/144)
```

```
C     WRITE (6,816) DELPH
C16   FORMAT(T10,'DELPH =',T17,F20.7)
      DELPP=DELPH*DELTAH
      DIFF=ABS(DELPP-DELP)
      IF(DIFF.GT.1.0) GO TO 20037
C     WRITE (6,815) DELPP
C15   FORMAT(T10,'GRADM =',T17,F10.5)
      GO TO 900
C
900   DEPTH1=DEPTH1+DELTAH
      P2=P1+DELPP
      WRITE(6,180)DEPTH1,P2,VSL,VSG,XLDEN,AGDEN,RSAVG,BOAVG
180   FORMAT(3X,8(F7.2,2X))
C
      IF(DEPTH1.GE.TOTDEP) GO TO 1831
      GO TO 1832
1831  DEPTH2=DEPTH1-TOTDEP
      DDD1=DEPTH2/DELTAH
      DDD2=DDD1*DELPP
      P2=P2-DDD2
      DEPTH1=DEPTH1-DEPTH2
C
C
1832  IF(IPROF.EQ.1) WRITE(15,184)DEPTH1,P2
184   FORMAT(3X,2(F9.2,2X))
C
      FGE=DEPTH1-TOTDEP
      IF(FGE.EQ.0.0) GO TO 250
C
C     CHECK IF TOTAL DEPTH IS REACHED
C     ASSUME P1 EQUAL TO P2 AND DEPTH1 EQUAL TO DEPTH2 AND ITERATE
      P1=P2
      T1=T2
      DELP=25
C
      GO TO 11
250   BHFP=P2
C     GO TO 50003
C0001 WRITE(15,50006) NITR
C0006 FORMAT(2X,I3,2X,'MAX NUMB OF ITR HAS BEEN EXE')
C     STOP
C
C0003 RETURN
      RETURN
      END
```

```
C     ***********************************************************
C     *                                                         *
C     *              BEGGS AND BRILL CORRELATION                *
C     *                                                         *
C     ***********************************************************
C     BEGGS
      SUBROUTINE BEGGS(VS,RESTMP,SURTMP,P1,DEPTH1,OILRTE,WTRRTE,DIMTB,
     &API,GOR,DIMTSG,DIMTBG,SPGWTR,SPGGAS,STNOIL,STNWTR,BW,EE,
     &DELP,DELTAH,G,GC,T1,TOTDEP,DIMTB2,DEPTB2,BHFP,IPROF)
C
      THETA=90.
C
C     STEP : 1 CALCULATE SPECIFIC GRAVITY OF OIL
C
      SPGOIL=141.5/(131.5+API)
C     WRITE (6,101) SPGOIL
C01   FORMAT(T10,' SPGOIL =',T17,F10.5)
C
C     STEP : 2 CALCULATE GLR WOR WCUT TOTAL LIQUID AND FLUID GRADIENT
C
      GLR=GOR*(OILRTE/(OILRTE+WTRRTE))
C     WRITE (6,102) GLR
C02   FORMAT(T10,' GLR =',T17,F10.5)
      WOR=WTRRTE/OILRTE
      DEPTH1=0
C     WRITE (6,103) WOR
C03   FORMAT(T10,' WOR =',T17,F10.5)
      WCUT=WTRRTE/(OILRTE+WTRRTE)
C     WRITE (6,104) WCUT
C04   FORMAT(T10,' WCUT =',T17,F10.5)
      TOTLIQ=OILRTE+WTRRTE
C     WRITE (6,105) TOTLIQ
C05   FORMAT(T10,' TOTLIQ =',T17,F10.1)
      APRXGD=.433*WCUT+SPGOIL*.433*(1.0-WCUT)
C     WRITE (6,106) APRXGD
C06   FORMAT(T10,' APRXGD =',T17,F10.5)
C     WRITE (6,107) DIAM
C07   FORMAT(T10,' DIAM =',T17,F10.5)
C
C     STEP : 4 CALCULATE MASS ASSOCIATED WITH 1 STB OF LIQUID
C
      AMASS=((SPGOIL*350.0)*(1.0-WCUT))
      BMASS=SPGWTR*350.0*WCUT
      CMASS=0.0764*GLR*SPGGAS
      TM=AMASS+BMASS+CMASS
C     WRITE (6,108) TM
C08   FORMAT(T10,' TM   =',T17,F10.5)
C
C     STEP : 5 CALCULATE MASS FLOW RATE
C
      W1=TM*TOTLIQ
```

```
C     WRITE (6,109) W1
C09   FORMAT(T10,' W1    =',T17,F10.0)
C
C     STEP : 6 CALCULATE TEMPERATURE GRADIENT
C
      TEMGRD=(RESTMP-SURTMP)/TOTDEP
C     WRITE (6,110) TEMGRD
C10   FORMAT(T10,' TEMGRD=',T17,F10.5)
C     WRITE (6,111) T1
C11   FORMAT(T10,' T1    =',T17,F10.5)
C
C     STEP : 7 CALCULATE AVERAGE TEMP AND AVERAGE PRESS
C
11    DELP=DELTAH*APRXGD
      DELP=25
      GO TO 16111
16110 DELP=DELPP
C     STEP : 3 CALCULATE HYDRAULIC DIAMETER
C              DIMTSG: INSIDE DIAMETER OF THE CASING
C              DIMTBG: OUTSIDE DIAMETER OF THE TUBING
C              DIMTB : INSIDE DIAMETER OF THE TUBING
C
C     CALCULATE THE AREA OF FLOW
C
16111 IF(DIMTSG.EQ.0.0) GO TO 12
      AREA=(22/7)*((DIMTSG**2-DIMTBG**2)/4)
      GO TO 14
12    IF(DEPTH1.LE.DEPTB2) GO TO 938
      DIAM=DIMTB2
      GO TO 14001
938   DIAM=DIMTB
14001 AREA=22*DIAM**2/(4*7)
14    CONTINUE
C     WRITE (6,112) DELP
C12   FORMAT(T10,' DELP  =',T17,F10.5)
      T2=T1+TEMGRD*DELTAH
C     WRITE (6,113) T2
C13   FORMAT(T10,' T2    =',T17,F10.5)
C13   TAVG=(T1+T2)/2
      TAVG=(T1+T2)/2
C     WRITE (6,114) TAVG
C14   FORMAT(T10,' TAVG  =',T17,F10.5)
      P2=P1+DELP
C     WRITE (6,115) P2
C15   FORMAT(T10,' P2    =',T17,F20.5)
C     WRITE (6,116) P1
C16   FORMAT(T10,' P1    =',T17,F20.5)
      PAVG=(P1+P2)/2+14.7
C     PAVG=(P1+P2)/2
C     WRITE (6,117) PAVG
C17   FORMAT(T10,' PAVG  =',T17,F20.5)
```

```
C
C     STEP : 8 CALCULATE SOLUTION GAS AT AVGP P1 P2
C
19    X1=PAVG/18
      X2=(10**((.0125*(API))))
      X3=(10**(0.00091*(TAVG)))
      X4=((X1*(X2/X3))**(1/0.83))
      RSAVG=SPGGAS*X4
      IF(RSAVG.LE.GOR) GO TO 1111
      RSAVG=GOR
C111  WRITE (6,118) RSAVG
C18   FORMAT(T10,' RSAVG =',T17,F10.5)
C     P1
C     X5=P1/18
1111  X5=P1/18
      X6=(10**((.0125*(API))-(0.00091*T1)))
      X7=(((X5*X6))**(1/0.83))
      RS1=SPGGAS*X7
      IF(RS1.LE.GOR) GO TO 20
      RS1=GOR
C0    WRITE (6,119) RS1
C19   FORMAT(T10,' RS1   =',T17,F10.5)
C     P2
C     X9=P2/18
20    X9=P2/18
      X10=(10**((.0125*(API))-(0.00091*T2)))
      X11=(((X9*X10))**(1/0.83))
      RS2=SPGGAS*X11
      IF(RS2.LE.GOR) GO TO 21
      RS2=GOR
C1    WRITE (6,120) RS2
C20   FORMAT(T10,' RS2   =',T17,F10.5)
C     CONTINUE
C
C     STEP : 9 CALCULATE FORM. VOL. FACTOR AT PAVG,TAVG P1,T1 P2,T2
C
21    FAVG=((RSAVG*((SPGGAS/SPGOIL)**0.5))+(1.25*TAVG))
C     WRITE(6,990)FAVG
C90   FORMAT(3X,(F8.2,3X))
      BOAVG=(0.972+((0.000147)*((FAVG**1.175))))
C     WRITE (6,121) BOAVG
C21   FORMAT(T10,' BOAVG =',T17,F10.5)
      F1=((RS1*((SPGGAS/SPGOIL)**0.5))+(1.25*T1))
      BO1=(0.972+((0.000147)*((F1**1.175))))
C     WRITE (6,122) BO1
C22   FORMAT(T10,' BO1   =',T17,F10.5)
      F2=((RS2*((SPGGAS/SPGOIL)**0.5))+(1.25*T2))
      BO2=(0.972+((0.000147)*((F2**1.175))))
C     WRITE (6,123) BO2
C23   FORMAT(T10,' BO2   =',T17,F10.5)
C
```

```
C     STEP : 10 CALCULATE THE DENSITY OF THE LIQUID PHASE
C
      G1=(SPGOIL*(62.4)+(RSAVG*SPGGAS*(0.0764))/(5.614))
      G2=((G1/BOAVG)*(1-WCUT))
      G3=((SPGWTR)*(62.4)*(WCUT))
      XLDEN=(G2+G3)
C     WRITE (6,124) XLDEN
C24   FORMAT(T10,'XLDEN  =',T17,F10.5)
C     AT P1
      G4=(SPGOIL*(62.4)+(RS1*SPGGAS*(0.0764))/(5.614))
      G5=((G4/BO1)*(1-WCUT))
      G6=((SPGWTR)*(62.4)*(WCUT))
      DEN1=(G5+G6)
C     WRITE (6,125) DEN1
C25   FORMAT(T10,' DEN1  =',T17,F10.5)
C     AT P2
      G7=(SPGOIL*(62.4)+(RS2*SPGGAS*(0.0764))/(5.614))
      G8=((G7/BO2)*(1-WCUT))
      G9=((SPGWTR)*(62.4)*(WCUT))
      DEN2=(G8+G9)
C     WRITE (6,126) DEN2
C26   FORMAT(T10,' DEN2  =',T17,F10.5)
C
C     CALCULATE GAS COMPRESSIBILITY FACTOR AT PAVG,TAVG P1,T1 P2,T2
C
      PPC=(709.604-58.718*(SPGGAS))
      TPC=(170.491+307.344*(SPGGAS))
      APR=PAVG/PPC
      ATR=(TAVG+460)/TPC
      PR1=(P1+14.7)/PPC
      TR1=(T1+460)/TPC
      PR2=(P2+14.7)/PPC
      TR2=(T2+460)/TPC
C     COEFFICIENTS
      A1=0.31506237
      A2=-1.04670990
      A3=-0.57832729
      A4=0.53530771
      A5=-0.61232032
      A6=-0.10488813
      A7=0.68157001
      A8=0.68446549
C     AT PAVG TAVG  ASSUME Z=1.0
      PR=APR
      TR=ATR
      AZ=1.0
15    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
```

```
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 30
      AZ=CZ
      GO TO 15
30    AVGZ=CZ
C     WRITE (6,127) AVGZ
C27   FORMAT(T10,' AVGZ  =',T17,F10.5)
C     AT P1 T1
      PR=PR1
      TR=TR1
      AZ=1.0
25    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 35
      AZ=CZ
      GO TO 25
35    Z1=CZ
C     WRITE (6,128) Z1
C28   FORMAT(T10,' Z1    =',T17,F10.5)
C     AT P2 T2
      PR=PR2
      TR=TR2
      AZ=1.0
45    CPR=(0.27*PR)/(AZ*TR)
      AK1=1+(A1+A2/TR+A3/(TR**3))*CPR+(A4+A5/TR)*(CPR**2)
      AK2=(A5*A6*(CPR**5)/TR)+(A7*(CPR**3)/(TR**3))
      AK3=(1+A8*(CPR**2))*(EXP(-A8*(CPR**2)))
      CZ=AK1+(AK2*AK3)
      ZDIF=ABS(CZ-AZ)
      IF(ZDIF.LE.0.0001)  GO TO 40
      AZ=CZ
      GO TO 45
40    Z2=CZ
C     WRITE (6,129) Z2
C29   FORMAT(T10,' Z2    =',T17,F10.5)
C     CALCULATE AVERAGE GAS DENSITY
      AGDEN=SPGGAS*0.0764*(PAVG/14.7)*(520/(TAVG+460))*(1/AVGZ)
C     WRITE (6,130) AGDEN
C30   FORMAT(T10,' AGDEN =',T17,F10.5)
C
C     CALCULATE AVERAGE VISCOSITY OF OIL
C
      S=3.0324-0.02023*(API)
      Y=10**(S)
      X=Y*(T1**(-1.163))
      ADOILV=(10**X)-1
      A=10.715*((RSAVG+100)**(-0.515))
```

```
      B=5.44*((RSAVG+150)**(-0.338))
      AOILV=(A*(ADOILV**B))
C     WRITE (6,131) AOILV
C31   FORMAT(T10,'AOILV =',T17,F10.5)
C
C     CALCULATE AVERAGE WATER VISCOSITY
C
      AWTRV=EXP(1.003-1.479E-2*TAVG+1.982E-5*(TAVG**(-2)))
C     WRITE (6,132) AWTRV
C32   FORMAT(T10,'AWTRV =',T17,F10.5)
C
C     CALCULATE LIQUID MIXTURE VISCOSITY
C
      ALIQV=AOILV*(1-WCUT)+AWTRV*(WCUT)
C     WRITE (6,133) ALIQV
C33   FORMAT(T10,'ALIQV =',T17,F10.5)
C
C     CALCULATE LIQUID MIXTURE SURFACE TENSION
C
      STLIQM=STNOIL*(1-WCUT)+STNWTR*(WCUT)
C     WRITE (6,134) STLIQM
C34   FORMAT(T10,'STLIQM=',T17,F10.5)
C
C     CALCULATE LIQUID VISCOSITY NUMBER
C
      VLN=0.15726*ALIQV*((1/(XLDEN*STLIQM**3))**0.25)
C     WRITE (6,135) VLN
C35   FORMAT(T10,'VLN   =',T17,F10.5)
C
C     CALCULATE VISCOSITY NUMBER CORRECTION FACTOR CNL
C
      A = 0.01001681
      B = -0.01522753
      C = -0.03911264
      D = -0.02739780
      E = -0.007981444
      F = -0.000842104
C     CNLB = B*(ALOG10(VLN))
C     CNLC = C*((ALOG10(VLN))**2)
C     CNLD = D*((ALOG10(VLN))**3)
C     CNLE = E*((ALOG10(VLN))**4)
C     CNLF = F*((ALOG10(VLN))**5)
C     CNL = A+CNLB+CNLC+CNLD+CNLE+CNLF
C     WRITE (6,136) CNL
C36   FORMAT(T10,'CNL   =',T17,F10.5)
C
C     CALCULATE SUPERFICIAL LIQUID VELOCITY
C
      BW=1.0
      VSL=5.61*((OILRTE+WTRRTE)/(86400*AREA))
     **(BOAVG*(1-WCUT)+BW*(WCUT))
```

```
C     WRITE (6,138) VSL
C38   FORMAT(T10,'VSL=',T17,F10.5)
      VSL1=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO1*(1-WCUT)+BW*(WCUT))
C     WRITE (6,139) VSL1
C39   FORMAT(T10,'VSL1  =',T17,F10.5)
      VSL2=5.61*((OILRTE+WTRRTE)/(86400*AREA))*(BO2*(1-WCUT)+BW*(WCUT))
C     WRITE (6,140) VSL2
C40   FORMAT(T10,'VSL2  =',T17,F10.5)
C
C     CALCULATE LIQUID VELOCITY NUMBER
C
      ANLV=1.938*VSL*((XLDEN/STLIQM)**0.25)
C     WRITE (6,141) ANLV
C41   FORMAT(T10,'ANLV  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT PAVG AND TAVG
C
      VSG=(OILRTE*(GOR-RSAVG)/(86400*AREA))*
     *(14.7/(PAVG))*((TAVG+460)/520)*(AVGZ)
C     WRITE (6,142) VSG
C42   FORMAT(T10,'VSG  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P1 AND T1
C
      VSG1=((OILRTE+WTRRTE)*(GLR-RS1*(1-WCUT))/(86400*AREA))*
     *(14.7/P1)*((T1+460)/520)*(Z1)
C     WRITE (6,143) VSG1
C43   FORMAT(T10,'VSG1  =',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL GAS VELOCITY AT P2 AND T2
C
      VSG2=((OILRTE+WTRRTE)*(GLR-RS2*(1-WCUT))/(86400*AREA))*
     *(14.7/P2)*((T2+460)/520)*(Z2)
C     WRITE (6,144) VSG2
C44   FORMAT(T10,'VSG2  =',T17,F10.5)
C
C     CALCULATE GAS VELOCITY NUMBER
C
      ANGV=1.938*VSG*((XLDEN/STLIQM)**0.25)
C     WRITE (6,145) ANGV
C45   FORMAT(T10,'ANGV  =',T17,F10.5)
C
C     CALCULATE QL AND QG
C
      QL=(6.49E-5)*((OILRTE*BOAVG)+(WTRRTE*BW))
C     WRITE (6,149) QL
C149  FORMAT(T10,'QL    =',T17,F10.5)
      QG=(3.27E-7)*(AVGZ)*((OILRTE)*(GOR-RSAVG)*(1.0))*
     *((TAVG+460)/PAVG)
C     WRITE (6,150) QG
C150   FORMAT(T10,'QG    =',T17,F10.5)
```

```
      IF(QG.LE.0.0) GO TO 60
      GO TO 13100
60    QG=0.0
13100 QT=QL+QG
C     WRITE (6,151) QT
C151   FORMAT(T10,'QT    =',T17,F10.5)
C
C     CALCULATE THE MOLECULAR WT OF THE GAS
C
18    GMWT=SPGGAS*29
C     WRITE (6,165) GMWT
C165   FORMAT(T10,'GMWT  =',T17,F10.5)
C     CALCULATE VISCOSITY OF THE GAS
C     XXX=3.5+986/(TAVG+460)+0.01*GMWT
      C1=TAVG+460
      C2=986/C1
      C3=0.01*GMWT
      XXX=3.5+C2+C3
      GAMMA=2.4-0.2*XXX
C     AKKK=(9.4+0.02*GMWT)*(TAVG+460)**1.5/
C    *(209+19*GMWT+(TAVG+460))
      D1=TAVG+460
      D2=D1**1.5
      D3=0.02*GMWT
      D4=D3+9.4
      D5=D4+D2
      D6=19*GMWT
      D7=209+D6
      D8=D7+D1
      AKKK=D5/D8
C     AGASVI=AKKK*0.0001*EXP(XXX*((AGDEN*454/30.8**3)**GAMMA))
      E1=AGDEN*454
      E2=30.8**3
      E3=E1/E2
      E4=E3**GAMMA
      E5=E4*XXX
      E6=EXP(E5)
      AGASVI=AKKK*0.0001*E6
C     WRITE (6,166) AGASVI
C166   FORMAT(T10,'AGASVI=',T17,F10.5)
C
C     CALCULATE THE SUPERFICIAL MIXTURE VELOCITY
C
      VM=VSL+VSG
C
C     ****************************************************************
C
C     CALCULATE THE LIQUID,GAS AND TOTAL MASS FLUX RATES
      GL=XLDEN*VSL
      GG=AGDEN*VSG
      GM=GL+GG
```

```
C
C     ********************************************************************
C     CALCULATE LAMDA
C
      ALAMDA=QL/(QL+QG)
C
C     ********************************************************************
C     CALCULATE FROUDE NUMBER
C
      ANFR=(VM**2)/(G*DIAM)
C
C     ********************************************************************
C
C     CALCULATE THE MIXTURE VISCOSITY (GAS AND LIQUID)
      XX=ALIQV*ALAMDA
      YY=AGASVI*(1-ALAMDA)
      ZZ=XX+YY
      UM=(6.72E-4)*ZZ
C
C     ***********************************************
C     CALCULATE NO SLIP REYNOLD NUMBER
C
      ANRENS=GM*DIAM/UM
      REN=ANRENS
      AOO=1.983*VSL
      APP=(XLDEN/STLIQM)**0.25
      ANLV=AOO*APP
C
C     ***********************************************
C     CALCULATE PARAMETERS TO DETERMINE FLOW PATTERNS
C
      ALL=ALAMDA**0.302
      AL1=316*ALL
C
      AKK=ALAMDA**(-2.4684)
      AL2=AKK*0.0009252
C
      AMM=ALAMDA**(-1.4516)
      AL3=AMM*0.10
C
      AQQ=ALAMDA**(-6.738)
      AL4=0.5*AQQ
C     ***********************************************
C     *                                             *
C     *          DETERMINE FLOW PATTERNS            *
C     *                                             *
C     ***********************************************
      IF(ALAMDA.LT.0.01) GO TO 10001
C
      IF(ALAMDA.GE.0.01.AND.ANFR.LE.AL2) GO TO 500
C
```

```
      IF(ALAMDA.GE.0.01.AND.ANFR.LE.AL3) GO TO 600
C
      IF(ALAMDA.GE.0.01.AND.ALAMDA.LT.0.4) GO TO 10002
C
      IF(ALAMDA.GE.0.4) GO TO 10003
C
10001 IF(ANFR.LT.AL1) GO TO 500
C
      IF(ANFR.GE.AL1) GO TO 800
C
10002 IF(ANFR.GT.AL3.AND.ANFR.LE.AL1) GO TO 700
C
      GO TO 800
C     700
10003 IF(ANFR.GT.AL3.AND.ANFR.LE.AL4) GO TO 700
C
      GO TO 800
C
C     ****************************************************
C     COEFFICIENTS FOR DIFFERENT FLOW PATTERNS
C     ****************************************************
C
C     ****************************************************
C     SEGREGATED  SUBSCRIPT: A
C     ****************************************************
500   AA=0.98
      AB=0.4846
      AC=0.0868
      AD=0.011
      AE=-3.768
      AF=3.539
      AG=-1.614
C     ******************************************************
C     CALCULATE HORIZONTAL HOLD UP FOR SEGREGATED FLOW
C     ******************************************************
      DD=ALAMDA**AB
      DD1=AA*DD
      DD2=ANFR**AC
      HLOS=DD1/DD2
      IF(HLOS.LT.ALAMDA) GO TO 16100
      GO TO 16101
16100 HLOS=ALAMDA
C     ******************************************************
C     CAL THE INCLINA CORR. FACTOR FOR SEGREGATED FLOW
C     ******************************************************
16101 CX=ANFR**AG
      CY=ANLV**AF
      CW=ALAMDA**AE
      WW=AD*CX*CY*CW
      CR=ALOG(WW)
      CN=1-ALAMDA
```

```
      CS=CR*CN
      IF(CS.LT.0.0) GO TO 16001
      GO TO 16002
16001 CS=0.0
C     ***********************************************
C     CAL THE LIQUID HOLDUP INCLINA CORR FACTOT
C           FOR SEGREGATED FLOW
C     ***********************************************
16002 R1=1.8*THETA
      R2A=(R1*22/(7*180))
      R2=SIN(R2A)
      R3=R2**3
      R4=0.3333*R3
      R5=R2-R4
      R6=CS*R5
      PHAIS=1.0+0.3*CS
C     ***********************************************
C     CAL THE LIQUID HOLDUP AND TWO PHASE DENSITY
C           FOR SEGREGATED FLOW
C     ***********************************************
      HL=HLOS*PHAIS
C
      QM=HL*XLDEN
      QN=AGDEN*(1.0-HL)
      TPDEN=QM+QN
C     ***********************************************
C     CAL THE FRICTION FACTOR RATIO
C           FOR SEGREGATED FLOW
C     ***********************************************
      Z1=HL**2
      Y=ALAMDA/Z1
C
      IF(Y.GT.1.0.AND.Y.LT.1.2) GO TO 11001
      Z2=ALOG(Y)
      Z3=3.182*Z2
      Z4=-0.0523+Z3
      Z5=Z2**2
      Z6=0.8725*Z5
      Z7=Z2**4
      Z8=0.01853*Z7
      Z9=Z4-Z6+Z8
      S=Z2/Z9
      GO TO 11002
11001 SR=2.2*Y
      SR1=SR-1.2
      S=ALOG(SR1)
11002 FRATIO=EXP(S)
C
C     ***********************************************
C     CAL NO-SLIP FRICTION FACTOR
C           FOR SEGREGATED FLOW
```

```
C     **************************************************
      TT1=ALOG10(ANRENS)
      TT2=4.5223*TT1
      TT3=TT2-3.8215
      TT4=ANRENS/TT3
      TT5=ALOG10(TT4)
      TT6=2*TT5
      TT7=TT6**2
      FNS=1/TT7
C
C     ************************************************
C     CALCULATE THE TWO PHASE FRICTION FACTOR
C          FOR SEGREGATED FLOW
C     ************************************************
      FTP=FNS*FRATIO
C     ************************************************
C     ************************************************
C     ******  FF USING MOODY CHART         **********
C     ************************************************
C     ************************************************
C     ************************************************
      EE= .00045
      RR=EE/DIAM
      IF(REN.LE.2000) GO TO 16401
      GO TO 16402
16401 FF=64/REN
      GO TO 16405
16402 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16406 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16405
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16406
      FF=FGI
16405 FTP=FF

C
C     ************************************************
```

```
C       CALCULATE THE DELTA PRESSURE
C            FOR SEGREGATED FLOW
C       ****************************************
C
        RR1=TPDEN*VM*VSG
        RR2=RR1/(PAVG*GC*144)
        RR3=1-RR2
        RR4=FTP*GM*VM
        RR5=RR4/(2*GC*DIAM)
        RR6=G/GC
        RR6A=THETA*22/(7*180)
C       RR7=RR6*TPDEN*SIN(RR6A)
C       RR7=TPDEN*1.0
        RR8=RR7+RR5
        RR9=DELTAH*RR8
        DELPP=RR9/RR3
        DELPP=DELPP/144
C
        GO TO 900
C       ****************************************
C       ****************************************
C       ****                           *********
C       ****       TRANSITION REGION   *********
C       ****                           *********
C       ****************************************
C       SEGREGATED  SUBSCRIPT: A
C       ****************************************
600     AA=0.98
        AB=0.4846
        AC=0.0868
        AD=0.011
        AE=-3.768
        AF=3.539
        AG=-1.614
C       *******************************************
C       CALCULATE HORIZONTAL HOLD UP FOR SEGREGATED FLOW
C       *******************************************
        DD=ALAMDA**AB
        DD1=AA*DD
        DD2=ANFR**AC
        HLOST=DD1/DD2
        IF(HLOST.LT.ALAMDA) GO TO 16102
        GO TO 16103
16102 HLOST=ALAMDA
C       *******************************************
C       CAL THE INCLINA CORR. FACTOR FOR SEGREGATED FLOW
C       *******************************************
16103 CX=ANFR**AG
        CY=ANLV**AF
        CW=ALAMDA**AE
        WW=AD*CX*CY*CW
```

```
      CR=ALOG(WW)
      CN=1-ALAMDA
      CST=CR*CN
      IF(CST.LT.0.0) GO TO 16003
      GO TO 16004
16003 CST=0.0
C     ***********************************************
C     CAL THE LIQUID HOLDUP INCLINA CORR FACTOT
C           FOR SEGREGATED FLOW
C     ***********************************************
16004 R1=1.8*THETA*22/(7*180)
      R2=SIN(R1)
      R3=R2**3
      R4=0.3333*R3
      R5=R2-R4
      R6=CST*R5
C     PHAIST=1.0+R6
      PHAIST=1.0+0.3*CST
C     ***********************************************
C     CAL THE LIQUID HOLDUP AND TWO PHASE DENSITY
C           FOR SEGREGATED FLOW
C     ***********************************************
      HLST=HLOST*PHAIST
C
C
C     **********************************************
C     INTERMITTENT SUBSCRIPT: B
C     **********************************************
      BA=0.845
      BB=0.5351
      BC=0.0173
      BD=2.96
      BE=0.305
      BF=-0.4473
      BG=0.0978
C     ***********************************************
C     CALCULATE HORIZONTAL HOLD UP FOR INTERMITTENT FLOW
C     ***********************************************
      DD=ALAMDA**BB
      DD1=BA*DD
      DD2=ANFR**BC
      HLOIT=DD1/DD2
      IF(HLOIT.LT.ALAMDA) GO TO 16104
      GO TO 16105
16104 HLOIT=ALAMDA
C     ***********************************************
C     CAL THE INCLINA CORR. FACTOR FOR INTERMITTENT FLOW
C     ***********************************************
16105 CX=ANFR**BG
      CY=ANLV**BF
      CW=ALAMDA**BE
```

```
      WW=BD*CX*CY*CW
      CR=ALOG(WW)
      CN=1-ALAMDA
      CIT=CR*CN
      IF(CIT.LT.0.0) GO TO 16005
      GO TO 16006
16005 CIT=0.0
C     **********************************************
C     CAL THE LIQUID HOLDUP INCLINA CORR FACTOT
C           FOR INTERMITTENT FLOW
C     **********************************************
16006 R1=1.8*THETA*22/(7*180)
      R2=SIN(R1)
      R3=R2**3
      R4=0.3333*R3
      R5=R2-R4
      R6=CIT*R5
C     PHAIIT=1.0+R6
      PHAIIT=1.0+0.3*CIT
C     **********************************************
C     CAL THE LIQUID HOLDUP AND THE TWO PHASE DENSITY
C           FOR TRANSITION REGION
C     **********************************************
      HLIT=HLOIT*PHAIIT
C
C
      RRR1=AL3-ANFR
      RRR2=AL3-AL2
      RRR3=RRR1/RRR2
      RRR4=1.0-RRR3
      HL=RRR3*HLST+RRR4*HLIT
      QM=HL*XLDEN
      QN=AGDEN*(1.0-HL)
      TPDEN=QM+QN
C     **********************************************
C     CAL THE FRICTION FACTOR RATIO
C           FOR TRANSITION FLOW
C     **********************************************
      Z1=HL**2
      Y=ALAMDA/Z1
      IF(Y.GT.1.0.AND.Y.LT.1.2) GO TO 15003
      Z2=ALOG(Y)
      Z3=3.182*Z2
      Z4=-0.0523+Z3
      Z5=Z2**2
      Z6=0.8725*Z5
      Z7=Z2**4
      Z8=0.01853*Z7
      Z9=Z4-Z6+Z8
      S=Z2/Z9
      GO TO 15004
```

```
15003 SR=2.2*Y
      SR1=SR-1.2
      S=ALOG(SR1)
15004 FRATIO=EXP(S)
C
C     ***********************************************
C     CAL NO-SLIP FRICTION FACTOR
C           FOR TRANSITION FLOW
C     ***********************************************
      TT1=ALOG10(ANRENS)
      TT2=4.5223*TT1
      TT3=TT2-3.8215
      TT4=ANRENS/TT3
      TT5=ALOG10(TT4)
      TT6=2*TT5
      TT7=TT6**2
      FNS=1/TT7
C
C     *********************************************
C     CALCULATE THE TWO PHASE FRICTION FACTOR
C          FOR TRANSITION FLOW
C     *********************************************
      FTP=FNS*FRATIO
C
C     *********************************************
C     *********************************************
C     ******  FF USING MOODY CHART         **********
C     *********************************************
C     *********************************************
C     *********************************************
      EE= .00045
      RR=EE/DIAM
      IF(REN.LE.2000) GO TO 16411
      GO TO 16412
16411 FF=64/REN
      GO TO 16415
16412 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16416 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
```

```
      IF(DIFF.LE.0.0001) GO TO 16415
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16416
      FF=FGI
16415 FTP=FF
C
C
C     **********************************************
C     CALCULATE THE DELTA PRESSURE
C          FOR TRANSITION FLOW
C     **********************************************
C
      RR1=TPDEN*VM*VSG
      RR2=RR1/(PAVG*GC*144)
      RR3=1-RR2
      RR4=FTP*GM*VM
      RR5=RR4/(2*GC*DIAM)
      RR6=G/GC
      RR6A=THETA*22/(7*180)
      RR7=TPDEN*1.0
      RR8=RR7+RR5
      RR9=DELTAH*RR8
      DELPP=RR9/RR3
      DELPP=DELPP/144
C
      GO TO 900
C
C
C
C
C     **********************************************
C     INTERMITTENT SUBSCRIPT: B
C     **********************************************
700   BA=0.845
      BB=0.5351
      BC=0.0173
      BD=2.96
      BE=0.305
      BF=-0.4473
      BG=0.0978
C     ************************************************
C     CALCULATE HORIZONTAL HOLD UP FOR INTERMITTENT FLOW
C     ************************************************
      DD=ALAMDA**BB
      DD1=BA*DD
      DD2=ANFR**BC
      HLOI=DD1/DD2
      IF(HLOI.LT.ALAMDA) GO TO 16106
      GO TO 16107
16106 HLOI=ALAMDA
```

```
C     ******************************************************
C     CAL THE INCLINA CORR. FACTOR FOR INTERMITTENT FLOW
C     ******************************************************
16107 CX=ANFR**BG
      CY=ANLV**BF
      CW=ALAMDA**BE
      WW=BD*CX*CY*CW
      CR=ALOG(WW)
      CN=1-ALAMDA
      CI=CR*CN
      IF(CI.LT.0.0) GO TO 16007
      GO TO 16008
16007 CI=0.0
C     ******************************************************
C     CAL THE LIQUID HOLDUP INCLINA CORR FACTOT
C           FOR INTERMITTENT FLOW
C     ******************************************************
16008 R1=1.8*THETA*22/(7*180)
      R2=SIN(R1)
      R3=R2**3
      R4=0.3333*R3
      R5=R2-R4
      R6=CI*R5
C     PHAII=1.0+R6
      PHAII=1.0+0.3*CI
C     ******************************************************
C     CAL THE LIQUID HOLDUP AND THE TWO PHASE DENSITY
C           FOR INTERMITTENT FLOW
C     ******************************************************
      HL=HLOI*PHAII
C
      QM=HL*XLDEN
      QN=AGDEN*(1.0-HL)
      TPDEN=QM+QN
C     ******************************************************
C     CAL THE FRICTION FACTOR RATIO
C           FOR INTERMITTENT FLOW
C     ******************************************************
      Z1=HL**2
      Y=ALAMDA/Z1
      IF(Y.GT.1.0.AND.Y.LT.1.2) GO TO 11003
      Z2=ALOG(Y)
      Z3=3.182*Z2
      Z4=-0.0523+Z3
      Z5=Z2**2
      Z6=0.8725*Z5
      Z7=Z2**4
      Z8=0.01853*Z7
      Z9=Z4-Z6+Z8
      S=Z2/Z9
      GO TO 11004
```

```
11003 SR=2.2*Y
      SR1=SR-1.2
      S=ALOG(SR1)
11004 FRATIO=EXP(S)
C
C     **************************************************
C     CAL NO-SLIP FRICTION FACTOR
C           FOR INTERMITTENT FLOW
C     **************************************************
      TT1=ALOG10(ANRENS)
      TT2=4.5223*TT1
      TT3=TT2-3.8215
      TT4=ANRENS/TT3
      TT5=ALOG10(TT4)
      TT6=2*TT5
      TT7=TT6**2
      FNS=1/TT7
C
C     ************************************************
C     CALCULATE THE TWO PHASE FRICTION FACTOR
C          FOR INTERMITTENT FLOW
C     ************************************************
      FTP=FNS*FRATIO
C     ************************************************
C     ************************************************
C     ******  FF USING MOODY CHART         **********
C     ************************************************
C     ************************************************
C     ************************************************
      EE= .00045
      RR=EE/DIAM
      IF(REN.LE.2000) GO TO 16421
      GO TO 16422
16421 FF=64/REN
      GO TO 16425
16422 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16426 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16425
```

```
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16426
      FF=FGI
16425 FTP=FF
C
C
C
C     *************************************************
C     CALCULATE THE DELTA PRESSURE
C          FOR INTERMITTENT FLOW
C     *************************************************
C
      RR1=TPDEN*VM*VSG
      RR2=RR1/(PAVG*GC*144)
      RR3=1-RR2
      RR4=FTP*GM*VM
      RR5=RR4/(2*GC*DIAM)
      RR6=G/GC
      RR6A=THETA*22/(7*180)
      RR7=TPDEN*1.0
      RR8=RR7+RR5
      RR9=DELTAH*RR8
      DELPP=RR9/RR3
      DELPP=DELPP/144
C
      GO TO 900
C
C     *************************************************
C     DISTRIBUTED  SUBSCRIPT: C
C     *************************************************
800   CA=1.065
      CB=0.5824
      CC=0.0609
C     ***************************************************
C     CALCULATE HORIZONTAL HOLD UP FOR DISTRIBUTED FLOW
C     ***************************************************
      DD=ALAMDA**CB
      DD1=CA*DD
      DD2=ANFR**CC
      HLOD=DD1/DD2
      IF(HLOD.LT.ALAMDA) GO TO 16108
      GO TO 16109
16108 HLOD=ALAMDA
C     ***************************************************
C     NO INCLINA CORR. FACTOR FOR DISTRIBUTED FLOW
C     ***************************************************
16109 CD=0.0
C     *************************************************
C     ***************************************************
C     CAL THE LIQUID HOLDUP INCLINA CORR FACTOT
```

```
C           FOR DISTRIBUTED FLOW
C      ************************************************
       PHAID=1.0+0.0
C      ************************************************
C      CAL THE LIQUID HOLDUP AND THE TWO PHASE DENSITY
C           FOR DISTRIBUTED FLOW
C      ************************************************
       HL=HLOD*PHAID
C
       QM=HL*XLDEN
       QN=AGDEN*(1.0-HL)
       TPDEN=QM+QN
C      ************************************************
C      CAL THE FRICTION FACTOR RATIO
C           FOR DISTRIBUTED FLOW
C      ************************************************
       Z1=HL**2
       Y=ALAMDA/Z1
       IF(Y.GT.1.0.AND.Y.LT.1.2) GO TO 11005
       Z2=ALOG(Y)
       Z3=3.182*Z2
       Z4=-0.0523+Z3
       Z5=Z2**2
       Z6=0.8725*Z5
       Z7=Z2**4
       Z8=0.01853*Z7
       Z9=Z4-Z6+Z8
       S=Z2/Z9
       GO TO 11006
11005  SR=2.2*Y
       SR1=SR-1.2
       S=ALOG(SR1)
11006  FRATIO=EXP(S)
C
C      ************************************************
C      CAL NO-SLIP FRICTION FACTOR
C           FOR DISTRIBUTED FLOW
C      ************************************************
       TT1=ALOG10(ANRENS)
       TT2=4.5223*TT1
       TT3=TT2-3.8215
       TT4=ANRENS/TT3
       TT5=ALOG10(TT4)
       TT6=2*TT5
       TT7=TT6**2
       FNS=1/TT7
C
C      **********************************************
C      CALCULATE THE TWO PHASE FRICTION FACTOR
C          FOR DISTRIBUTED FLOW
C      **********************************************
```

```
      FTP=FNS*FRATIO
C     ***********************************************
C     ***********************************************
C     ******  FF USING MOODY CHART         **********
C     ***********************************************
C     ***********************************************
C     ***********************************************
      EE= .00045
      RR=EE/DIAM
      IF(REN.LE.2000) GO TO 16431
      GO TO 16432
16431 FF=64/REN
      GO TO 16435
16432 I=1
      FGI=REN**0.32
      FGI=0.5/FGI
      FGI=0.0056+FGI

16436 B11=FGI**0.5
      B12=B11*REN
      B13=9.34/B12
      B14=RR+B13
      B15=ALOG10(B14)
      B16=B15*2.0
      DEN=1.14-B16
      FF=(1./DEN)
      FF=FF**2
      DIFF=ABS(FGI-FF)
      IF(DIFF.LE.0.0001) GO TO 16435
      FGI=(FGI+FF)/2.0
      I=I+1
      IF(I.LT.10) GO TO 16436
      FF=FGI
16435 FTP=FF
C
C
C     ***********************************************
C     CALCULATE THE DELTA PRESSURE
C          FOR DISTRIBUTED FLOW
C     ***********************************************
C
      RR1=TPDEN*VM*VSG
      RR2=RR1/(PAVG*GC*144)
      RR3=1-RR2
      RR4=FTP*GM*VM
      RR5=RR4/(2*GC*DIAM)
      RR6=G/GC
      RR6A=THETA*22/(7*180)
      RR6AB=SIN(RR6A)
      RR7=TPDEN*1.0
      RR8=RR7+RR5
```

```
      RR9=DELTAH*RR8
      DELPP=RR9/RR3
      DELPP=DELPP/144
C     WRITE (16,9166) RR3
C166  FORMAT(T10,'RR3   =',T17,F10.5)
C
      GO TO 900
C
C
C     WRITE (8,817) DELTAH
C17   FORMAT(T10,'DELTAH=',T17,F20.9)
C     CALCULATE TOTAL DEPTH
900   DXDX=ABS(DELP-DELPP)
      IF(DXDX.GT.0.01) GO TO 16110
      DEPTH1=DEPTH1+DELTAH
      P2=P1+DELPP
C
      IF(DEPTH1.GE.TOTDEP) GO TO 1831
      GO TO 1832
1831  DEPTH2=DEPTH1-TOTDEP
      DDD1=DEPTH2/DELTAH
      DDD2=DDD1*DELPP
      P2=P2-DDD2
      DEPTH1=DEPTH1-DEPTH2
C
1832  IF(IPROF.EQ.1) WRITE(16,908)DEPTH1,P2
908   FORMAT(3X,2(F9.2,2X))
      FGE=DEPTH1-TOTDEP
      IF(FGE.EQ.0.0) GO TO 1000
C
C
C     CHECK IF TOTAL DEPTH IS REACHED
C     IF(DEPTH1.GE.TOTDEP) GO TO 1000
C     ASSUME P1 EQUAL TO P2 AND DEPTH1 EQUAL TO DEPTH2 AND ITERATE
      P1=P2
      T1=T2
      GO TO 11
C1000 STOP    JUST FOR TEST
1000  BHFP=P2
      RETURN
      END
```

APPENDIX B

TEST DATA

DESCRIPTION

FWHP	: Flowing well head pressure, psig
OIL RATE	: Oil rate, STBOPD
WATER RATE	: Water rate, BBLWPD
GOR	: Gas-oil ratio, SCF/STB
TUBING 1	: The first tubing diameter from surface, ft.
TUBING 2	: The second tubing diameter from surface, ft.
DCPTH 1	: The length of the first tubing size, ft.
DCPTH 2	: The length of both the first and second tubings, ft
WATER DNSTY	: Water density, gm/cc
OIL GRAV	: Oil gravity, gm/cc
SURF TEMP	: Surface temperature, °F
BOTM TEMP	: Flowing bottom hole temperature, °F
MBHP	: Measured flowing bottom hole pressure, psig

Table 1: Field Production Data

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
1	220	10200	1450	590	0.318	0.318	8000	6220	36.5	1.07	0.73	158	208	2437
2	288	17076	960	517	0.318	0.318	8000	6094	36.5	1.07	0.73	160	206	2510
3	340	7612	505	580	0.318	0.318	8000	6781	36.5	1.07	0.73	156	208	2975
4	470	11151	0	591	0.330	0.330	8000	6527	36.5	1.07	0.73	157	210	2440
5	450	1080	7240	623	0.330	0.330	8000	6444	36.5	1.07	0.73	150	209	3105
6	215	5184	4416	470	0.330	0.330	8000	6401	36.5	1.07	0.73	153	209	2280
7	330	15274	1	440	0.318	0.318	8000	6743	36.5	1.07	0.73	157	212	2555
8	220	5750	6300	700	0.318	0.318	8000	6701	36.5	1.07	0.73	152	212	2686
9	205	3300	1700	561	0.318	0.166	3882	6446	36.5	1.07	0.73	150	209	2460
10	340	11153	23	548	0.318	0.318	8000	6732	36.5	1.07	0.73	155	212	2600
11	85	240	2774	450	0.330	0.330	8000	6450	36.5	1.07	0.73	148	209	2723
12	180	712	7790	728	0.330	0.330	8000	6394	36.5	1.07	0.73	149	209	3308
13	220	13655	0	556	0.330	0.330	8000	6128	36.5	1.07	0.73	155	206	2269
14	230	3100	0	535	0.166	0.166	8000	6277	36.5	1.07	0.73	151	208	2590
15	220	886	5578	999	0.330	0.330	8000	6778	36.5	1.07	0.73	155	208	2692
16	230	14364	0	489	0.318	0.318	8000	6643	36.5	1.07	0.73	158	211	2337
17	170	2700	4100	675	0.318	0.318	8000	6930	36.5	1.07	0.73	152	214	2754
18	270	4680	3120	478	0.318	0.318	8000	6194	36.5	1.07	0.73	150	207	2116
19	150	887	252	567	0.318	0.318	8000	6200	36.5	1.07	0.73	150	207	1227
20	150	584	2974	599	0.203	0.203	8000	6347	36.5	1.07	0.73	150	208	2582
21	330	5637	3758	603	0.330	0.330	8000	6549	36.5	1.07	0.73	152	210	2648
22	540	14590	0	480	0.318	0.318	8000	6300	36.5	1.07	0.73	158	208	2656
23	200	5450	5950	581	0.318	0.318	8000	6506	36.5	1.07	0.73	151	210	2414
24	200	5600	5400	634	0.318	0.318	8000	6498	36.5	1.07	0.73	152	210	2497
25	195	2987	92	622	0.330	0.166	5679	6323	36.5	1.07	0.73	150	208	1449
26	260	11456	2006	440	0.318	0.318	8000	6578	36.5	1.07	0.73	155	211	2430
27	195	8490	5361	520	0.318	0.318	8000	6081	36.5	1.07	0.73	154	206	2491
28	340	21800	800	619	0.530	0.330	1624	6001	36.5	1.07	0.73	160	205	2287
29	280	1600	6600	523	0.330	0.330	8000	6751	36.5	1.07	0.73	152	208	2835
30	220	9293	6379	509	0.330	0.330	8000	6400	36.5	1.07	0.73	159	209	2699

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
31	200	12938	300	486	0.318	0.318	8000	6265	36.5	1.07	0.73	158	208	2161
32	280	15655	287	478	0.330	0.330	8000	6308	36.5	1.07	0.73	158	208	2429
33	300	11132	368	560	0.330	0.330	8000	6814	36.5	1.07	0.73	157	213	2180
34	470	1958	6199	600	0.330	0.330	8000	6628	36.5	1.07	0.73	156	211	2894
35	270	2638	8160	764	0.330	0.330	8000	6594	36.5	1.07	0.73	156	211	2857
36	550	7507	0	600	0.330	0.330	8000	6541	36.5	1.07	0.73	156	210	2391
37	400	11521	1683	702	0.330	0.330	8000	6369	36.5	1.07	0.73	157	209	2444
38	285	11209	2859	489	0.330	0.330	8000	6200	36.5	1.07	0.73	157	207	2602
39	320	7797	4174	486	0.330	0.330	8000	6567	36.5	1.07	0.73	156	211	2790
40	260	12320	2030	515	0.330	0.330	8000	6400	36.5	1.07	0.73	157	209	2675
41	240	13513	100	540	0.318	0.318	8000	6626	36.5	1.07	0.73	157	211	2639
42	225	17125	366	515	0.318	0.318	8000	6500	36.5	1.07	0.73	157	210	2780
43	509	8469	1	500	0.330	0.330	8000	6194	36.5	1.07	0.73	155	207	1911
44	350	4048	172	736	0.318	0.166	2484	7025	36.5	1.07	0.73	153	215	2891
45	250	11119	740	562	0.318	0.318	8000	6263	36.5	1.07	0.73	156	208	2406
46	280	17100	0	536	0.318	0.318	8000	6675	36.5	1.07	0.73	158	207	2878
47	220	13728	0	526	0.318	0.318	8000	5995	36.5	1.07	0.73	157	205	2262
48	280	6900	215	540	0.318	0.318	8000	6623	36.5	1.07	0.73	154	211	2550
49	180	14927	564	550	0.318	0.318	8000	6450	36.5	1.07	0.73	156	209	2662
50	350	4000	5496	618	0.330	0.330	8000	6492	36.5	1.07	0.73	155	210	2633
51	195	8769	4854	515	0.330	0.330	8000	6600	36.5	1.07	0.73	156	211	2652
52	350	700	4200	650	0.318	0.166	6424	6579	36.5	1.07	0.73	151	211	2889
53	330	1192	5076	515	0.318	0.166	6424	6300	36.5	1.07	0.73	152	208	2658
54	240	4888	3024	527	0.318	0.318	8000	6350	36.5	1.07	0.73	156	208	2615
55	238	14244	264	570	0.330	0.318	8000	6650	36.5	1.07	0.73	157	211	2500
56	230	14360	0	500	0.330	0.330	8000	6731	36.5	1.07	0.73	157	212	2503
57	250	15702	0	503	0.330	0.330	8000	6594	36.5	1.07	0.73	158	211	2655
58	210	14242	0	470	0.318	0.318	8000	6857	36.5	1.07	0.73	157	209	2611
59	241	8696	1728	640	0.330	0.330	8000	6750	36.5	1.07	0.73	155	212	2240
60	340	3750	3214	653	0.330	0.330	8000	6826	36.5	1.07	0.73	153	213	2529

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
61	260	688	4459	580	0.330	0.249	6670	6724	36.5	1.07	0.73	152	212	3038
62	250	1300	3624	722	0.318	0.318	8000	6929	36.5	1.07	0.73	151	214	2681
63	245	12750	70	530	0.318	0.318	8000	6461	36.5	1.07	0.73	156	210	2603
64	200	2275	625	562	0.318	0.318	8000	6328	36.5	1.07	0.73	150	208	1502
65	200	5100	1	471	0.318	0.318	8000	6100	36.5	1.07	0.73	150	206	1343
66	190	9600	1200	570	0.330	0.330	8000	6638	36.5	1.07	0.73	155	211	2459
67	189	12700	0	515	0.330	0.330	8000	6500	36.5	1.07	0.73	156	210	2384
68	160	2300	1900	400	0.318	0.318	8000	6127	36.5	1.07	0.73	152	206	1612
69	10	368	192	603	0.203	0.203	8000	6413	36.5	1.07	0.73	140	209	1305
70	180	6106	1	515	0.318	0.318	8000	5385	36.5	1.07	0.73	153	199	1115
71	168	742	299	451	0.203	0.203	8000	6427	36.5	1.07	0.73	146	209	1579
72	225	2000	7900	715	0.318	0.318	8000	6591	36.5	1.07	0.73	157	211	3000
73	285	5300	2800	550	0.318	0.318	8000	6446	36.5	1.07	0.73	155	209	2446
74	285	8616	2500	491	0.318	0.318	8000	6294	36.5	1.07	0.73	156	208	2343
75	285	2739	3377	500	0.330	0.330	8000	6533	36.5	1.07	0.73	153	210	2484
76	220	853	1782	538	0.330	0.330	8000	6269	36.5	1.07	0.73	150	208	2478
77	200	8128	3095	460	0.318	0.318	8000	5875	36.5	1.07	0.73	157	204	2050
78	210	2198	3230	480	0.330	0.330	8000	6555	36.5	1.07	0.73	154	211	2370
79	190	8009	3013	451	0.330	0.330	8000	6434	36.5	1.07	0.73	157	209	2118
80	180	1477	3397	448	0.330	0.330	8000	6208	36.5	1.07	0.73	151	207	2273
81	190	2680	2331	540	0.330	0.330	8000	6516	36.5	1.07	0.73	151	210	2332
82	200	11390	1210	450	0.318	0.318	8000	6312	36.5	1.07	0.73	157	208	2342
81	205	2020	6128	468	0.330	0.330	8000	6586	36.5	1.07	0.73	155	211	2723
83	260	2649	5051	466	0.330	0.330	8000	6579	36.5	1.07	0.73	154	211	2261
84	220	14874	150	423	0.318	0.318	8000	6280	36.5	1.07	0.73	156	208	2189
85	350	3600	3500	520	0.330	0.330	8000	6840	36.5	1.07	0.73	153	213	2596
86	240	6798	4902	515	0.318	0.318	8000	6780	36.5	1.07	0.73	157	213	2775
87	220	7336	4717	491	0.318	0.318	8000	6033	36.5	1.07	0.73	157	205	2240
88	215	3193	2613	467	0.318	0.318	8000	5779	36.5	1.07	0.73	152	203	1666
89	300	12684	453	490	0.330	0.330	8000	6071	36.5	1.07	0.73	157	206	2288
90	185	344	3956	515	0.330	0.330	8000	6452	36.5	1.07	0.73	150	210	2766

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
91	380	15526	0	545	0.330	0.330	8000	5988	36.5	1.07	0.73	158	205	2554
92	284	9884	2716	372	0.330	0.330	8000	6737	36.5	1.07	0.73	157	212	2426
93	290	13621	0	469	0.318	0.318	8000	6345	36.5	1.07	0.73	157	208	2472
94	190	6000	7350	534	0.330	0.330	8000	6496	36.5	1.07	0.73	157	210	2531
95	190	1535	2922	506	0.318	0.318	8000	5973	36.5	1.07	0.73	151	205	2259
96	180	4760	6340	515	0.330	0.330	8000	6500	36.5	1.07	0.73	156	210	2484
97	170	6377	4731	467	0.318	0.318	8000	5550	36.5	1.07	0.73	156	200	1999
98	195	9307	819	520	0.318	0.318	8000	5585	36.5	1.07	0.73	155	201	1570
99	280	16437	0	495	0.330	0.330	8000	6427	36.5	1.07	0.73	158	209	2483
101	180	8668	165	520	0.318	0.318	8000	6665	36.5	1.07	0.73	155	212	2702
102	200	18603	531	559	0.318	0.318	8000	6500	36.5	1.07	0.73	158	210	2667
103	280	7290	3904	515	0.318	0.318	8000	6500	36.5	1.07	0.73	157	210	2504
104	180	6903	1658	560	0.318	0.318	8000	6535	36.5	1.07	0.73	153	210	2620
105	190	6396	5256	667	0.318	0.318	8000	6780	36.5	1.07	0.73	155	213	2522
106	195	15000	400	536	0.318	0.318	8000	6440	36.5	1.07	0.73	157	209	2286
107	235	6400	0	470	0.318	0.318	8000	6523	36.5	1.07	0.73	152	210	2508
108	220	9200	200	550	0.318	0.318	8000	6453	36.5	1.07	0.73	153	210	2492
109	200	6400	4600	515	0.330	0.330	8000	6664	36.5	1.07	0.73	154	212	2448
110	200	4518	1163	520	0.318	0.318	8000	6248	36.5	1.07	0.73	152	207	1869
111	185	2500	3300	488	0.318	0.318	8000	6451	36.5	1.07	0.73	151	210	2720
112	230	13400	2629	584	0.318	0.318	8000	5827	36.5	1.07	0.73	156	203	2367
113	320	6813	69	514	0.330	0.166	5107	6810	36.5	1.07	0.73	152	213	2675
114	210	1328	375	408	0.318	0.166	6390	6659	36.5	1.07	0.73	150	212	1986
115	190	5699	5880	540	0.330	0.330	8000	6381	36.5	1.07	0.73	155	209	2447
116	200	220	1392	520	0.203	0.203	8000	6621	36.5	1.07	0.73	150	211	2879
117	220	12335	1073	500	0.318	0.318	8000	6591	36.5	1.07	0.73	156	211	2448
118	200	12147	1830	459	0.330	0.330	8000	6879	36.5	1.07	0.73	156	214	2411
119	205	13986	113	518	0.318	0.318	8000	6625	36.5	1.07	0.73	156	211	2447
120	180	13972	213	470	0.318	0.318	8000	5488	36.5	1.07	0.73	158	200	2009

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
121	190	4606	7410	548	0.318	0.318	8000	6568	36.5	1.07	0.73	156	211	2581
122	170	2809	617	494	0.330	0.166	3766	6694	36.5	1.07	0.73	155	212	2106
123	200	22161	2739	514	0.523	0.318	1721	6599	36.5	1.07	0.73	160	211	2643
124	180	4964	6403	486	0.330	0.330	8000	6840	36.5	1.07	0.73	155	213	2833
125	220	21282	85	518	0.523	0.318	1736	6651	36.5	1.07	0.73	160	212	2536
126	175	4432	334	482	0.523	0.318	1806	6304	36.5	1.07	0.73	151	208	1325
127	80	500	6300	515	0.330	0.330	8000	6578	36.5	1.07	0.73	151	211	2733
128	205	22968	232	492	0.523	0.318	1547	6589	36.5	1.07	0.73	160	211	2479
129	165	2785	40	584	0.166	0.166	8000	6644	36.5	1.07	0.73	151	211	2673
130	75	1608	0	895	0.166	0.166	8000	6204	36.5	1.07	0.73	151	207	1763
131	250	8739	2494	448	0.330	0.330	8000	6286	36.5	1.07	0.73	155	208	2229
132	260	17651	0	368	0.318	0.318	8000	5758	36.5	1.07	0.73	158	203	2348
133	170	6800	152	525	0.318	0.318	8000	6550	36.5	1.07	0.73	154	210	1968
134	165	7400	152	525	0.318	0.318	8000	6544	36.5	1.07	0.73	153	210	1990
135	730	18474	0	512	0.523	0.318	6180	6219	36.5	1.07	0.73	158	207	2445
136	220	4093	1347	437	0.318	0.249	142	5990	36.5	1.07	0.73	152	205	2002
137	240	1650	7150	724	0.330	0.166	6704	6980	36.5	1.07	0.73	154	215	3038
138	175	13135	0	503	0.318	0.318	8000	6483	36.5	1.07	0.73	154	210	2556
139	240	8500	5400	674	0.318	0.318	8000	6423	36.5	1.07	0.73	155	209	2438
140	320	8200	1450	544	0.318	0.318	8000	6543	36.5	1.07	0.73	154	210	2392
141	175	6840	5078	590	0.330	0.330	8000	6447	36.5	1.07	0.73	154	209	2423
142	200	3400	7900	680	0.318	0.318	8000	6062	36.5	1.07	0.73	154	206	2453
143	210	9300	822	540	0.318	0.318	8000	6664	36.5	1.07	0.73	153	212	2572
144	200	10000	3100	530	0.318	0.318	8000	6336	36.5	1.07	0.73	155	208	2482
145	220	19000	132	550	0.318	0.249	5860	6073	36.5	1.07	0.73	157	206	2475
146	200	13971	659	520	0.318	0.318	8000	6563	36.5	1.07	0.73	155	211	2639
147	590	13898	43	585	0.318	0.318	8000	6582	36.5	1.07	0.73	155	211	2685
148	200	5164	2611	503	0.318	0.249	6173	6273	36.5	1.07	0.73	154	208	2017
149	210	6632	5582	416	0.318	0.249	6400	6439	36.5	1.07	0.73	155	209	2425
150	325	14104	588	449	0.318	0.249	5932	6022	36.5	1.07	0.73	156	205	2332

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
151	195	8934	3866	469	0.318	0.249	6533	6574	36.5	1.07	0.73	155	211	2415
152	175	6836	5934	550	0.523	0.318	1810	6606	36.5	1.07	0.73	155	211	2183
153	210	13500	2300	520	0.318	0.318	8000	6450	36.5	1.07	0.73	156	209	2466
154	250	3050	3000	597	0.330	0.330	8000	6727	36.5	1.07	0.73	152	212	2449
155	540	13715	286	515	0.318	0.318	8000	6866	36.5	1.07	0.73	156	214	2986
156	240	15867	687	501	0.318	0.318	8000	6629	36.5	1.07	0.73	157	211	2684
157	265	20193	2267	505	0.523	0.318	1693	6237	36.5	1.07	0.73	159	207	2469
158	300	20581	21	464	0.523	0.318	1742	6263	36.5	1.07	0.73	159	208	2480
159	190	14072	128	473	0.523	0.318	1863	6080	36.5	1.07	0.73	157	206	1612
160	195	6300	950	534	0.318	0.166	6035	6388	36.5	1.07	0.73	153	209	2012
161	210	2992	5628	560	0.318	0.249	6484	6519	36.5	1.07	0.73	151	210	2402
162	200	19125	154	490	0.523	0.318	1948	6607	36.5	1.07	0.73	158	211	2323
163	260	16500	900	510	0.523	0.318	1784	6464	36.5	1.07	0.73	157	210	2430
164	520	13006	0	553	0.318	0.249	6773	6814	36.5	1.07	0.73	155	213	2943
165	200	9555	4287	456	0.523	0.318	1800	6575	36.5	1.07	0.73	155	211	2105
166	220	4413	4179	529	0.318	0.318	8000	6275	36.5	1.07	0.73	154	208	2231
167	260	11094	7231	520	0.523	0.318	1689	6511	36.5	1.07	0.73	158	210	2519
168	310	2700	6300	546	0.330	0.330	8000	6787	36.5	1.07	0.73	154	213	3038
169	240	18400	0	500	0.523	0.523	8000	6392	36.5	1.07	0.73	156	209	2242
170	185	7581	1301	512	0.523	0.318	1823	6537	36.5	1.07	0.73	154	210	1753
171	159	1670	0	604	0.249	0.166	233	6435	36.5	1.07	0.73	151	209	2030
172	235	8548	0	545	0.318	0.318	8000	6880	36.5	1.07	0.73	153	214	1888
173	320	10141	215	538	0.318	0.249	6905	6971	36.5	1.07	0.73	154	215	2403
174	190	3207	0	516	0.249	0.249	8000	6701	36.5	1.07	0.73	152	212	1998
175	260	4100	0	482	0.249	0.166	6578	7078	36.0	1.07	0.73	155	216	2076
176	282	4900	0	591	0.249	0.166	6309	6324	36.0	1.07	0.73	155	208	1480
177	355	12690	0	576	0.318	0.249	6592	6719	36.0	1.07	0.73	157	212	2573
178	275	10500	0	582	0.318	0.318	8000	6915	36.0	1.07	0.73	156	214	2341
179	500	9706	198	550	0.318	0.318	8000	6356	36.0	1.07	0.73	157	209	2292
180	330	7292	5400	539	0.330	0.249	6248	6274	36.0	1.07	0.73	156	208	2690

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
181	230	4358	2000	597	0.330	0.249	6054	6168	36.0	1.07	0.73	155	207	1734
182	590	14463	450	590	0.330	0.249	6619	6494	36.0	1.07	0.73	158	210	2694
183	180	2952	130	525	0.166	0.166	8000	6630	36.0	1.07	0.73	158	211	2710
184	250	15729	0	484	0.318	0.249	6452	6582	36.0	1.07	0.73	159	211	2553
185	200	10996	5063	487	0.330	0.330	8000	6700	36.0	1.07	0.73	157	212	2813
186	380	12111	637	567	0.318	0.249	6646	6836	36.0	1.07	0.73	158	213	2816
187	230	15918	0	613	0.330	0.330	8000	6629	36.0	1.07	0.73	159	211	2740
188	300	13500	0	600	0.318	0.318	8000	6357	36.0	1.07	0.73	158	209	2580
189	320	14301	1038	567	0.330	0.249	6492	6682	36.0	1.07	0.73	158	212	2636
190	260	15276	0	488	0.330	0.249	6686	6720	36.0	1.07	0.73	159	212	2694
191	280	14678	1452	504	0.330	0.249	6469	6300	36.0	1.07	0.73	158	208	2419
192	310	4898	1302	485	0.330	0.166	3826	6430	36.0	1.07	0.73	152	209	2479
193	300	4352	4683	623	0.318	0.249	6199	6290	36.0	1.07	0.73	152	208	2411
194	310	14866	1161	595	0.330	0.249	6623	6720	36.0	1.07	0.73	158	212	2716
195	300	2154	5310	552	0.318	0.249	6224	6253	36.0	1.07	0.73	155	208	2467
196	320	12520	0	510	0.318	0.249	6566	6665	36.0	1.07	0.73	157	212	2684
197	529	5877	6900	562	0.330	0.249	6635	6664	36.0	1.07	0.73	155	212	2653
198	280	12268	12	491	0.318	0.249	6343	6458	36.0	1.07	0.73	156	210	2237
199	249	18276	204	450	0.318	0.249	6377	6594	36.0	1.07	0.73	159	211	2936
200	330	9700	0	560	0.318	0.318	8000	6450	36.0	1.07	0.73	155	209	2476
201	260	12563	0	483	0.318	0.249	6722	6720	36.0	1.07	0.73	156	212	2707
202	210	8518	4368	505	0.330	0.249	6933	6965	36.0	1.07	0.73	157	215	2610
203	160	6670	1986	588	0.318	0.249	6763	6788	36.0	1.07	0.73	155	213	2023
204	195	11080	0	530	0.318	0.318	8000	6734	36.0	1.07	0.73	156	212	2092
205	760	1256	2634	645	0.318	0.318	8000	6285	36.0	1.07	0.73	150	208	2531
206	316	16218	0	586	0.318	0.249	6438	6555	36.0	1.07	0.73	158	211	2566
207	187	6434	3475	562	0.330	0.249	6633	7074	36.0	1.07	0.73	157	216	2228
208	365	11598	97	540	0.330	0.249	6856	6948	36.0	1.07	0.73	157	214	2783
209	150	2181	3467	535	0.330	0.249	6019	6935	36.0	1.07	0.73	155	214	2570
210	200	2910	3190	521	0.330	0.249	6576	6571	36.0	1.07	0.73	155	211	2654

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
211	250	11297	1869	522	0.330	0.249	6656	6688	36.0	1.07	0.73	157	212	2325
212	300	2741	2146	550	0.249	0.249	8000	6085	36.0	1.07	0.73	152	206	2125
213	250	8500	200	550	0.318	0.318	8000	6075	36.0	1.07	0.73	155	206	2213
214	240	15500	1	593	0.330	0.249	6277	6227	36.0	1.07	0.73	158	207	2281
215	200	1045	2	449	0.330	0.249	6406	7084	36.0	1.07	0.73	150	216	1674
216	312	7321	4173	550	0.330	0.330	8000	6550	36.0	1.07	0.73	158	210	2489
217	220	16882	0	588	0.318	0.318	8000	6694	36.0	1.07	0.73	159	212	2897
218	350	13200	201	595	0.337	0.249	6495	6521	36.0	1.07	0.73	158	210	2661
219	310	3334	834	582	0.330	0.330	8000	6114	36.0	1.07	0.73	153	206	1615
220	385	17435	0	540	0.523	0.318	2016	6802	36.0	1.07	0.73	158	213	2660
221	230	12400	1176	560	0.523	0.318	1984	6500	36.0	1.07	0.73	157	210	2652
222	470	14062	0	527	0.523	0.318	1865	6662	36.0	1.07	0.73	157	212	2472
223	450	12839	0	430	0.523	0.318	1969	6880	36.0	1.07	0.73	157	214	2114
224	530	10698	0	520	0.330	0.249	6879	7006	36.0	1.07	0.73	156	215	2604
225	570	12878	0	580	0.318	0.249	6745	6862	36.0	1.07	0.73	157	214	2706
226	380	14694	202	546	0.318	0.330	208	6594	36.0	1.07	0.73	158	211	2584
227	170	2848	20	648	0.166	0.166	8000	6528	36.0	1.07	0.73	158	210	2761
228	340	8329	834	564	0.330	0.166	6383	6910	36.0	1.07	0.73	156	214	2755
229	290	2800	43	547	0.166	0.166	8000	6600	36.0	1.07	0.73	158	211	2569
230	180	7480	1	607	0.249	0.249	8000	6406	36.0	1.07	0.73	156	209	2423
231	300	3052	108	575	0.166	0.166	8000	6654	36.0	1.07	0.73	159	212	2766
232	280	4975	864	640	0.249	0.166	4188	6627	36.0	1.07	0.73	157	211	2847
233	230	3624	3664	640	0.320	0.249	6420	6497	36.0	1.07	0.73	156	210	2427
234	280	4888	1008	659	0.318	0.166	4130	6570	36.0	1.07	0.73	156	211	2532
235	400	13240	576	560	0.318	0.249	6568	6700	36.0	1.07	0.73	158	212	2746
236	500	12416	1776	577	0.318	0.249	6568	6700	36.0	1.07	0.73	158	211	2791
237	260	13800	1200	673	0.330	0.249	6694	6725	36.0	1.07	0.73	159	212	2892
238	220	11562	992	588	0.330	0.249	6694	6720	36.0	1.07	0.73	158	212	2869
239	430	8427	5272	694	0.330	0.249	6550	6533	36.0	1.07	0.73	159	210	2772
240	400	8847	3791	525	0.330	0.249	6550	6730	36.0	1.07	0.73	159	212	2796

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
241	440	8111	4152	619	0.330	0.249	6550	6577	36.0	1.07	0.73	158	211	2721
242	230	1079	900	550	0.166	0.166	8000	6565	36.0	1.07	0.73	156	211	2641
243	420	16452	117	650	0.318	0.249	6636	6769	36.0	1.07	0.73	158	213	2758
244	350	12943	171	550	0.330	0.249	6900	6932	36.0	1.07	0.73	158	214	2431
245	210	1877	0	622	0.203	0.166	4353	6865	36.0	1.07	0.73	155	214	2199
246	250	14624	1256	551	0.330	0.330	8000	6518	36.0	1.07	0.73	157	210	2565
247	320	15598	328	663	0.330	0.330	8000	6521	36.0	1.07	0.73	157	210	2492
248	280	16048	152	514	0.330	0.249	6671	6703	36.0	1.07	0.73	157	212	2459
249	220	9276	5616	595	0.330	0.330	8000	6688	36.0	1.07	0.73	158	212	2621
250	280	13600	1608	470	0.330	0.249	6688	6721	36.0	1.07	0.73	158	212	2476
251	200	10300	3870	669	0.330	0.249	6365	6467	36.0	1.07	0.73	158	210	2478
252	270	18146	0	551	0.330	0.330	8000	6366	36.0	1.07	0.73	160	209	2542
253	250	14387	896	524	0.330	0.249	6680	6778	36.0	1.07	0.73	159	213	2452
254	200	6634	3859	592	0.330	0.249	6481	6505	36.0	1.07	0.73	157	210	2222
255	250	13100	2700	674	0.318	0.318	8000	6734	36.0	1.07	0.73	160	212	2612
256	200	7448	6036	647	0.318	0.249	6737	6764	36.0	1.07	0.73	160	213	2726
257	240	7154	3008	663	0.330	0.249	6599	6709	36.0	1.07	0.73	159	212	2255
258	280	6950	4528	544	0.318	0.249	6517	6558	36.0	1.07	0.73	159	211	2576
259	220	8045	4128	600	0.318	0.318	8000	6623	36.0	1.07	0.73	159	211	2624
260	170	2839	2761	550	0.330	0.249	6148	6128	36.0	1.07	0.73	156	206	1716
261	190	5036	820	510	0.318	0.330	6268	6342	36.0	1.07	0.73	156	208	1541
262	120	1038	501	457	0.318	0.330	6268	6289	36.0	1.07	0.73	152	208	1298
263	200	8418	94	500	0.318	0.330	6429	6539	36.0	1.07	0.73	158	210	1682
264	270	15370	600	640	0.318	0.330	6570	6629	36.0	1.07	0.73	160	211	2690
265	220	10273	4362	683	0.330	0.249	6436	6370	36.0	1.07	0.73	159	209	2326
266	250	10610	272	594	0.318	0.249	6409	6500	36.0	1.07	0.73	158	210	2324
267	295	19370	0	570	0.318	0.318	8000	6756	36.0	1.07	0.73	160	213	2770
268	320	17243	696	535	0.318	0.318	8000	6714	36.0	1.07	0.73	160	212	2805
269	215	14950	1315	643	0.318	0.249	6522	6646	36.0	1.07	0.73	159	211	2636
270	280	11553	824	561	0.330	0.249	6777	6803	36.0	1.07	0.73	158	213	2467

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
271	200	13050	488	556	0.330	0.249	6777	6754	36.0	1.07	0.73	158	213	2439
272	285	13893	2455	528	0.330	0.249	6777	6815	36.0	1.07	0.73	158	213	2679
273	280	15930	654	612	0.330	0.330	8000	6721	36.0	1.07	0.73	159	212	2517
274	180	10404	2172	570	0.330	0.249	6639	6758	36.0	1.07	0.73	158	213	2726
275	235	7315	3945	602	0.330	0.249	6681	6894	36.0	1.07	0.73	159	214	2587
276	200	17391	208	621	0.318	0.249	6678	6809	36.0	1.07	0.73	159	213	2554
277	200	13306	2688	729	0.330	0.249	6667	6507	36.0	1.07	0.73	159	211	2480
278	200	14050	1970	514	0.330	0.249	6687	6726	36.0	1.07	0.73	159	212	2583
279	300	14833	0	605	0.318	0.249	6690	6815	36.0	1.07	0.73	159	213	2699
280	300	15128	2850	557	0.330	0.249	6388	6419	36.0	1.07	0.73	159	209	2577
281	350	13824	3396	546	0.330	0.249	6388	6452	36.0	1.07	0.73	158	210	2651
282	230	17913	0	630	0.318	0.249	6560	6658	36.0	1.07	0.73	158	212	2676
283	240	17781	768	533	0.318	0.249	6638	6670	36.0	1.07	0.73	160	212	2672
284	220	16841	1053	606	0.330	0.249	6543	6579	36.0	1.07	0.73	158	211	2632
285	330	15975	10	551	0.318	0.318	8000	6708	36.0	1.07	0.73	159	212	2712
286	200	21462	1	570	0.318	0.318	8000	8580	36.0	1.07	0.73	158	211	2573
287	380	20785	0	560	0.523	0.318	2523	6625	36.0	1.07	0.73	160	211	2509
288	270	16785	0	569	0.318	0.318	6557	6583	36.0	1.07	0.73	150	211	2539
289	295	18811	1716	627	0.523	0.318	1974	6564	36.0	1.07	0.73	160	211	2360
290	340	20730	0	558	0.523	0.318	1987	6687	36.0	1.07	0.73	160	212	2370
291	260	16819	0	524	0.318	0.249	6229	6345	36.0	1.07	0.73	160	208	2596
292	240	12809	0	553	0.523	0.318	2013	6614	36.0	1.07	0.73	158	211	1705
293	220	13973	1	550	0.318	0.249	6495	6540	36.0	1.07	0.73	157	210	2304
294	270	19618	0	496	0.318	0.318	8000	6499	36.0	1.07	0.73	150	210	2671
295	270	18410	0	503	0.318	0.249	6623	6718	36.0	1.07	0.73	150	212	2641
296	170	6000	0	630	0.523	0.318	2368	6687	36.0	1.07	0.73	150	212	1171
297	520	7200	0	820	0.249	0.166	5783	5815	37.0	1.07	0.73	152	198	2471
298	540	9799	3755	863	0.318	0.203	6284	6431	37.0	1.07	0.73	153	209	2626
299	470	3000	0	800	0.166	0.166	8000	6454	37.0	1.07	0.73	153	207	2744
300	515	4200	1000	947	0.203	0.203	8000	6317	37.0	1.07	0.73	152	210	2610

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
301	510	12200	50	855	0.330	0.249	6429	6461	37.0	1.07	0.73	152	209	2717
302	830	13695	0	804	0.330	0.249	6429	6461	37.0	1.07	0.73	155	209	2663
303	560	1193	0	787	0.166	0.166	8000	6597	37.0	1.07	0.73	154	211	2740
304	570	2800	3200	858	0.318	0.249	5901	6017	37.0	1.07	0.73	155	205	2236
305	545	7300	940	858	0.249	0.249	8000	6350	37.0	1.07	0.73	155	209	2646
306	30	800	700	850	0.166	0.166	8000	6900	37.0	1.07	0.73	155	214	2039
307	560	15500	0	851	0.330	0.330	8000	6041	37.0	1.07	0.73	158	205	2544
308	580	15092	0	837	0.330	0.330	8000	6035	37.0	1.07	0.73	158	205	2533
309	550	7900	4100	876	0.330	0.249	6506	6546	37.0	1.07	0.73	155	211	2675
310	580	16389	0	811	0.318	0.249	5923	6049	37.0	1.07	0.73	156	205	2470
311	580	3830	0	635	0.330	0.249	6776	6804	37.0	1.07	0.73	150	213	1928
312	80	323	1119	999	0.166	0.166	8000	7100	37.0	1.07	0.73	155	215	2505
313	510	700	800	976	0.166	0.166	8000	6819	37.0	1.07	0.73	155	213	2875
314	530	1597	363	850	0.166	0.166	8000	6908	37.0	1.07	0.73	158	214	2660
315	720	14500	0	846	0.330	0.249	8000	6864	37.0	1.07	0.73	156	213	2738
316	620	6896	3000	840	0.330	0.330	8000	6902	37.0	1.07	0.73	158	214	2519
317	560	10000	2100	955	0.330	0.330	8000	6902	37.0	1.07	0.73	158	214	2557
318	680	4400	5200	970	0.330	0.249	6740	6767	37.0	1.07	0.73	152	212	2784
319	560	6000	600	860	0.330	0.166	5414	6916	37.0	1.07	0.73	153	214	2616
320	800	14800	0	850	0.318	0.318	8000	6834	37.0	1.07	0.73	155	215	2825
321	760	13200	0	850	0.318	0.318	8000	6826	37.0	1.07	0.73	155	215	2716
322	550	8434	3280	860	0.318	0.318	8000	6794	37.0	1.07	0.73	154	213	2851
323	650	13200	0	830	0.330	0.330	8000	6827	37.0	1.07	0.73	154	213	2939
324	920	9963	0	834	0.330	0.330	8000	6990	37.0	1.07	0.73	155	215	3019
325	540	14700	800	850	0.330	0.330	8000	6781	37.0	1.07	0.73	156	213	2707
326	400	4752	2700	798	0.318	0.318	8000	6180	37.0	1.07	0.73	152	208	2312
327	590	9800	4900	863	0.330	0.330	8000	6709	37.0	1.07	0.73	156	212	2776
328	555	20200	0	826	0.330	0.330	8000	6223	37.0	1.07	0.73	158	207	2533
329	530	14000	0	820	0.330	0.330	8000	6217	37.0	1.07	0.73	155	207	2628
330	530	19000	1800	870	0.530	0.330	2077	6891	37.0	1.07	0.73	158	214	2591

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
331	620	16100	900	818	0.330	0.249	6690	6748	37.0	1.07	0.73	157	212	2776
332	560	12600	3600	820	0.330	0.249	6690	6744	37.0	1.07	0.73	157	212	2773
333	580	18000	0	806	0.318	0.249	6374	6505	37.0	1.07	0.73	158	210	2758
334	590	18300	0	814	0.318	0.249	6374	6495	37.0	1.07	0.73	158	210	2820
335	620	9600	3400	845	0.318	0.318	8000	7028	37.0	1.07	0.73	155	215	2863
336	540	9902	4496	836	0.318	0.318	8000	6886	37.0	1.07	0.73	155	214	2820
337	540	15500	0	812	0.330	0.330	8000	6876	37.0	1.07	0.73	158	214	2769
338	670	4182	5044	860	0.330	0.249	6781	6825	37.0	1.07	0.73	153	214	2816
339	600	7400	4400	961	0.330	0.249	6781	6825	37.0	1.07	0.73	154	214	2773
340	550	2500	0	813	0.166	0.166	8000	6829	37.0	1.07	0.73	155	214	2959
341	570	3367	33	859	0.166	0.166	8000	6836	37.0	1.07	0.73	155	214	2988
342	800	14130	500	863	0.330	0.249	6756	6787	37.0	1.07	0.73	157	214	2838
343	630	15183	0	830	0.330	0.249	6756	6990	37.0	1.07	0.73	157	215	2890
344	570	12397	1672	858	0.318	0.318	8000	6163	37.0	1.07	0.73	156	207	2561
345	450	9504	1120	805	0.318	0.318	8000	6163	37.0	1.07	0.73	155	207	2299
346	570	10200	3900	860	0.330	0.330	8000	6897	37.0	1.07	0.73	156	214	2853
347	620	16000	0	825	0.330	0.249	6789	6818	37.0	1.07	0.73	158	213	2823
348	520	17200	735	804	0.318	0.249	6179	6307	37.0	1.07	0.73	153	208	2581
349	510	18437	0	835	0.318	0.318	8000	6307	37.0	1.07	0.73	150	208	2605
350	550	17394	0	785	0.330	0.249	6302	6334	37.0	1.07	0.73	153	208	2649
351	640	18780	0	820	0.318	0.318	8000	6328	37.0	1.07	0.73	150	208	2616
352	620	8177	4576	914	0.330	0.249	6824	6852	37.0	1.07	0.73	150	214	2698
353	530	12500	2300	887	0.330	0.249	6824	6875	37.0	1.07	0.73	152	214	2735
354	520	7900	6700	890	0.330	0.249	6033	6078	37.0	1.07	0.73	155	206	2511
355	555	13200	2646	811	0.330	0.249	6033	6084	37.0	1.07	0.73	155	206	2537
356	580	15770	0	860	0.318	0.318	8000	6563	37.0	1.07	0.73	157	211	2679
357	580	7900	0	896	0.318	0.318	8000	6557	37.0	1.07	0.73	157	211	2040
358	580	1566	124	860	0.318	0.249	6387	6498	37.0	1.07	0.73	157	211	1924
359	600	16500	100	820	0.523	0.318	2741	6562	37.0	1.07	0.73	156	211	2614
360	650	15400	0	760	0.330	0.249	6668	6704	37.0	1.07	0.73	157	212	2804

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
361	280	5500	0	928	0.330	0.249	6668	6700	37.0	1.07	0.73	153	212	1377
362	500	3100	0	927	0.249	0.249	8000	6724	37.0	1.07	0.73	152	215	1923
363	960	1855	0	860	0.203	0.203	8000	7043	37.0	1.07	0.73	150	210	2898
364	390	629	0	6	0.330	0.166	377	5024	30.0	1.07	0.82	105	163	2226
365	340	835	0	31	0.330	0.166	377	5024	30.0	1.07	0.82	105	163	2189
366	255	1258	0	31	0.330	0.166	377	5024	30.0	1.07	0.82	108	163	2128
367	408	1803	0	22	0.523	0.318	306	5220	30.0	1.07	0.82	107	163	2397
368	250	4016	0	22	0.523	0.318	306	5220	30.0	1.07	0.82	113	163	2250
369	122	6225	0	22	0.523	0.318	306	5220	30.0	1.07	0.82	113	163	2133
370	130	11258	0	120	0.330	0.330	8000	5050	30.0	1.07	0.82	103	162	2110
371	434	3155	0	120	0.318	0.318	8000	4550	30.0	1.07	0.82	121	163	2083
372	368	5966	0	120	0.318	0.318	8000	4550	30.0	1.07	0.82	127	163	2044
373	295	8367	0	120	0.318	0.318	8000	4550	30.0	1.07	0.82	134	163	2005
374	400	2187	0	120	0.318	0.318	8000	4950	30.0	1.07	0.82	105	162	2163
375	320	4025	0	120	0.318	0.318	8000	4950	30.0	1.07	0.82	124	162	2080
376	240	5684	0	120	0.318	0.318	8000	4950	30.0	1.07	0.82	129	162	1992
377	240	959	0	33	0.330	0.330	8000	5071	30.0	1.07	0.82	110	162	2191
378	225	2350	0	32	0.330	0.330	8000	5071	30.0	1.07	0.82	127	162	2082
379	120	2717	0	32	0.330	0.330	8000	5071	30.0	1.07	0.82	135	162	1945
380	350	4137	0	140	0.330	0.330	8000	5189	30.0	1.07	0.82	97	162	2278
381	268	7535	0	140	0.330	0.330	8000	5189	30.0	1.07	0.82	106	162	2219
382	188	9866	0	140	0.330	0.330	8000	5189	30.0	1.07	0.82	124	162	2157
383	460	2230	0	120	0.318	0.318	8000	4650	30.0	1.07	0.82	111	157	2143
384	390	4940	0	120	0.318	0.318	8000	4650	30.0	1.07	0.82	123	157	2084
385	290	9110	0	120	0.318	0.318	8000	4650	30.0	1.07	0.82	132	157	1984
386	340	1459	0	120	0.330	0.249	4888	5878	30.0	1.07	0.82	105	161	2072
387	260	2635	0	120	0.330	0.249	4888	5878	30.0	1.07	0.82	112	161	1952
388	282	989	10	120	0.330	0.330	8000	5050	30.0	1.07	0.82	106	161	2190
389	200	2350	118	120	0.330	0.330	8000	5050	30.0	1.07	0.82	115	162	2107
390	104	3614	217	120	0.330	0.330	8000	5050	30.0	1.07	0.82	125	162	1989

Table 1: Field Production Data (Continued)

WELL	FWHP	OIL RATE	WATER RATE	GOR	TUBING1	TUBING2	DEPTH1	DEPTH2	API	WATER DNSTY	OIL GRAV.	SURF. TEMP.	BOTM. TEMP.	MBHP
391	142	3647	0	120	0.318	0.318	8000	5066	30.0	1.07	0.82	122	162	1903
392	365	2357	0	120	0.318	0.318	8000	5126	30.0	1.07	0.82	115	162	2192
393	295	4007	0	120	0.318	0.318	8000	5126	30.0	1.07	0.82	123	162	2112
394	220	5990	0	120	0.318	0.318	8000	5126	30.0	1.07	0.82	129	162	2029
395	366	680	0	120	0.318	0.318	8000	5078	30.0	1.07	0.82	110	162	2173
396	332	1120	0	120	0.318	0.318	8000	5078	30.0	1.07	0.82	116	162	2136
397	302	1160	0	120	0.318	0.318	8000	5078	30.0	1.07	0.82	123	162	2099
398	340	1129	0	120	0.318	0.318	8000	4964	30.0	1.07	0.82	114	162	2163
399	290	2825	0	120	0.318	0.318	8000	4964	30.0	1.07	0.82	118	162	2102
400	215	4761	0	120	0.318	0.318	8000	4964	30.0	1.07	0.82	124	162	2011
401	285	434	0	194	0.318	0.318	8000	5050	30.0	1.07	0.82	104	162	2074
402	88	280	0	120	0.318	0.318	8000	5082	30.0	1.07	0.82	76	162	2024
403	235	942	0	120	0.318	0.318	8000	4949	30.0	1.07	0.82	99	162	1975
404	215	1041	0	120	0.318	0.318	8000	4949	30.0	1.07	0.82	100	162	1932
405	385	8224	0	120	0.330	0.330	8000	4704	30.0	1.07	0.82	122	162	1937
406	350	10123	0	120	0.330	0.330	8000	4704	30.0	1.07	0.82	118	162	1921
407	305	11506	0	120	0.330	0.330	8000	4704	30.0	1.07	0.82	119	162	1902
408	95	1890	0	120	0.330	0.330	8000	5100	30.0	1.07	0.82	108	162	1911
409	349	3549	0	95	0.330	0.330	8000	5100	30.0	1.07	0.82	138	162	2320
410	236	6981	0	96	0.330	0.330	8000	5100	30.0	1.07	0.82	150	162	2266
411	108	9702	0	96	0.330	0.330	8000	5100	30.0	1.07	0.82	156	162	2204
412	393	3562	0	120	0.318	0.318	8000	5100	30.0	1.07	0.82	107	162	2291
413	275	5723	0	120	0.318	0.318	8000	5100	30.0	1.07	0.82	124	162	2216
414	140	8033	0	120	0.318	0.318	8000	5100	30.0	1.07	0.82	135	162	2127